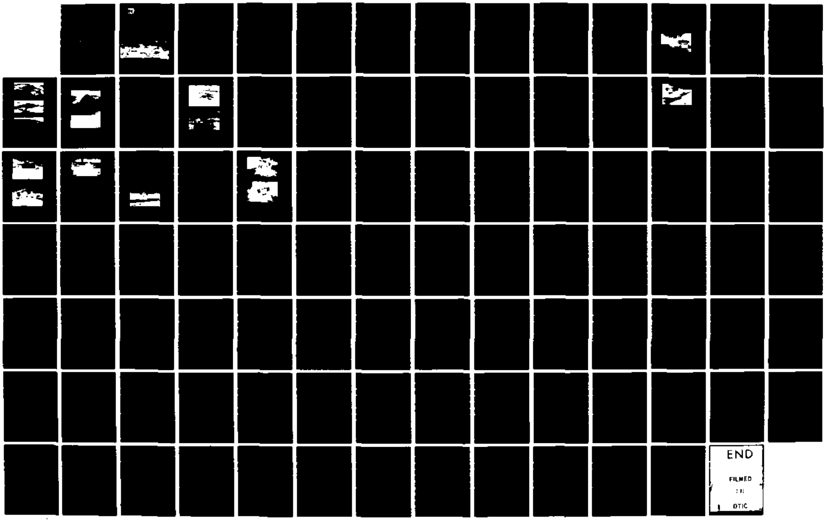
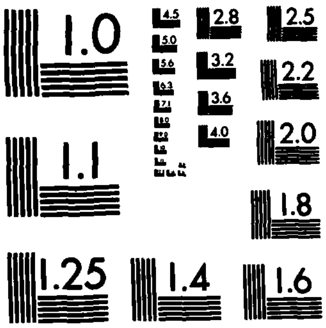
AD-A123 287 MOBILITY ASSESSMENT OF THE ROLAND WHEELED VEHICLE SYSTEM REPORT 1 RESULTS..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS GEOTE.. 1/1

UNCLASSIFIED B G SCHREINER ET AL. NOV 82 F/G 13/6 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TECHNICAL REPORT GL-82-12

MOBILITY ASSESSMENT OF THE ROLAND WHEELED VEHICLE SYSTEM

Report 1

RESULTS OF FIELD TESTS

by

Barton G. Schreiner and Charles E. Green

Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

November 1982

Report 1 of a Series

Prepared for U. S. Army Missile Command
Redstone Arsenal, Ala. 35809

Under Project No. A11DX588D1Q602

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report GL-82-12	2. GOVT ACCESSION NO. AD-A123287	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MOBILITY ASSESSMENT OF THE ROLAND WHEELED VEHICLE SYSTEM; Report 1, RESULTS OF FIELD TESTS		5. TYPE OF REPORT & PERIOD COVERED Report 1 of a series 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Barton G. Schreiner Charles E. Green		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Geotechnical Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project No. A11DX588D1Q602
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Missile Command Redstone Arsenal, Ala. 35809		12. REPORT DATE November 1982 13. NUMBER OF PAGES 89
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Army Mobility Model
Military vehicles
Mobility models
Vehicle performance

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A test program was conducted at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., to obtain mobility performance data for the ROLAND Wheeled Vehicle, a modified M812A1, 6x6 cargo chassis, with 11x20 tires and a gross weight of 50,239 lb. Static measurements of vehicle characteristics were made and field tests were conducted to: obtain experimental ride quality data on the driver's and commander's stations; to obtain vehicle handling data; and to provide limited test data that would indicate side slope, turning, and braking capabilities. Test results were used to develop ride and (Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued)

shock relations for use in the Army Mobility Model (AMM). The report describes the test program and methods presented, and summarizes measurements made in the dynamics, side slope, turning, and braking tests. Increased weight and center of gravity height do not significantly affect ride and shock dynamic responses as compared to the standard M813A1 5-ton, 6x6, cargo truck. Turning, braking, and side slope performances are moderately degraded.

PREFACE

The vehicle performance tests reported herein were conducted in March 1982 at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., for the U. S. Army Missile Command (MICOM), Redstone, Ala., under Project No. A11DX588D1Q602.

The overall field program was under the direct supervision of Mr. B. G. Schreiner, Chief, Engineering Test Group, Mobility Systems Division (MSD), Geotechnical Laboratory (GL), and under the general supervision of Mr. C. J. Nuttall, Jr., Chief, MSD, GL, and Dr. W. F. Marcuson III, Chief, GL. The field testing was directed by Mr. C. E. Green, MSD.

This report is the first report of a two-report series entitled "Mobility Assessment of the ROLAND Wheeled Vehicle System" and was prepared by Messrs. Schreiner and Green.

Acknowledgement is made to Mr. Douglas Tilden of the Boeing Aerospace Company for his assistance in this program.

COL Tilford C. Creel, CE, was Commander and Director of the WES during the conduct of this study and preparation of the report. Mr. Fred R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
feet per minute	0.3048	metres per minute
feet per second squared	0.3048	metres per second squared
horsepower (550 foot-pounds (force) per second)	745.6999	watts
horsepower (550 foot-pounds (force) per second) per ton (force)	83.82	watts per kilonewton
inches	2.54	centimetres
miles (U. S. statute)	1.609347	kilometres
miles (U. S. statute) per hour	1.609347	kilometres per hour
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
square inches	6.4516	square centimetres
tons (force)	8896.444	newtons
tons (2000 lb, mass)	907.1847	kilograms

MOBILITY ASSESSMENT OF THE ROLAND WHEELED VEHICLE SYSTEM

RESULTS OF FIELD TESTS

PART I: INTRODUCTION

Background

1. In February 1982, the Mobility Systems Division (MSD) of the Geotechnical Laboratory (GL), U. S. Army Engineer Waterways Experiment Station (WES), was contacted by the U. S. Army Missile Command (MICOM) and asked to conduct a mobility assessment study of the ROLAND All-Weather Short-Range Air Defense System (SHORADS). The ROLAND SHORADS system has been in existence for a number of years and was originally configured for production using the XM975 (M109 derivative) tracked vehicle as the carrier for the launcher system (fire unit). The ROLAND System, which is being produced for MICOM by Boeing Aerospace Company, Seattle, Wash., was recently restructured to have the fire unit transported by a wheeled vehicle for use by the Rapid Deployment Force (RDF). A trade-off study was conducted to determine if the wheeled vehicle carrier would meet requirements which included cost and schedule limitations. The carrier selected was an M812A1* military vehicle which had been used as the carrier for the HONEST JOHN missile system. The HONEST JOHN launchers were removed from the trucks and the trucks will be refurbished for ROLAND use.

2. Funds were provided by MICOM for WES to conduct field tests and assess the mobility performance of the ROLAND vehicle system. The field test results were used to develop the vehicle's ride dynamics and handling characteristics. The relations determined from the test data were used as input to the Army Mobility Model (AMM) (which gives similar predictions to the NATO Reference Mobility Model) which was used in the mobility assessment of the vehicle system.

---

* Developed as a carrier for the Ribbon bridge and later used as a carrier for the HONEST JOHN missile system.

Purpose

3. The purpose of the WES study was to:

a. Obtain experimental ride quality (ride and shock) data at the driver's and commander's stations to obtain handling (control and stability) data for the ROLAND Wheeled Vehicle;

b. Use the experimental data to develop the appropriate ride and shock relations for use in the AMM;

c. Provide acceleration data and strain gage data to Boeing for assessment of structural integrity;

d. Provide limited test data that would indicate side slope and turning capabilities of the proposed ROLAND Wheeled Vehicle; AND

e. Make mobility predictions of the ROLAND Wheeled Vehicle and other vehicles in a European and Mid-East scenario based on the AMM (see Report 2).

Scope

4. Static measurement of vehicle characteristics were made and field tests with a simulated ROLAND Wheeled Vehicle system were conducted on test courses at WES to obtain performance data (detailed test requirements are shown in Appendix A). The results from these performance tests were reduced, analyzed, and used as input to the AMM (AMC-74X version).

PART II: TEST PROGRAM

Test Vehicle

5. The ROLAND Wheeled Vehicle system tested in this study (Figure 1) was a modified M812A1 6x6 cargo truck chassis fitted with a simulated (weight, center of gravity, and size) fire unit. The test vehicle was tested at a gross weight of 50,239 lb* and with 11x20 tires inflated to a recommended cross-country pressure of 75 psi in the front (No. 1 axle) tires and 55 psi in the tires of the No. 2 and 3 axles. Appendix B presents the method by which the test vehicle's center of gravity was determined. General vehicle data are presented in Table 1. The vehicle data required for the AMC-74X mobility model are presented in Report 2.

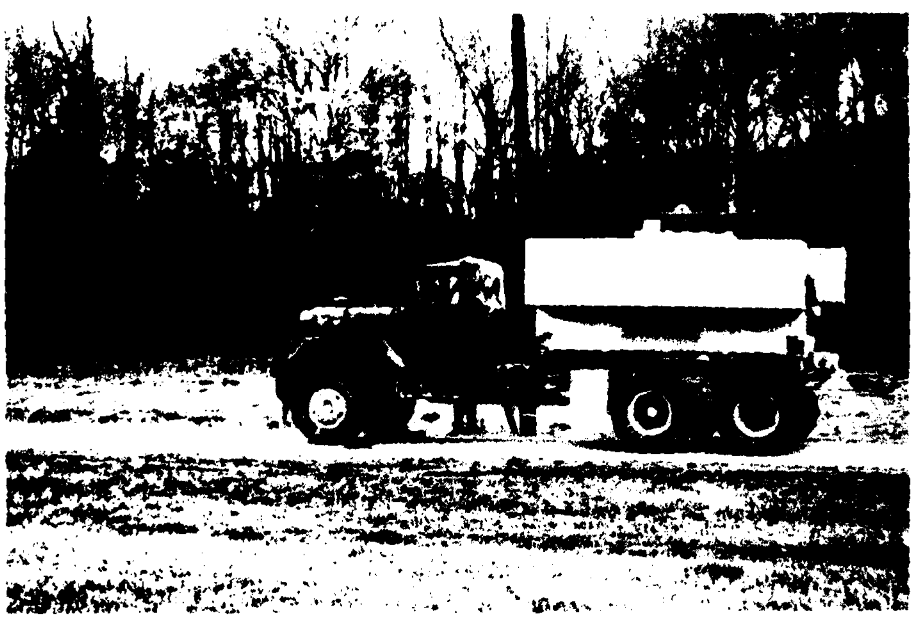


Figure 1. ROLAND Wheeled Vehicle system with simulated fire unit

---

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

Selection, Location, and Description of Test Courses

6. In selecting courses to develop the ride relations, courses were sought whose surfaces were firm and of approximately constant roughness throughout without evident pattern (i.e., had essentially random variations in local elevations). Also, each course was relatively level (no slope) for about 300 ft. Five courses were developed with individual roughness ranging from relatively smooth to rough. The locations of ride test courses are shown in Figure 2, with photographs of these courses presented in Figure 3.

7. The surface roughness of test courses 1, 2, and 4 was constructed in 1980 based on surface profiles measured from natural cross-country terrain. First, construction equipment was used to develop the basic surface roughness. Then dry cement was spread over the surface, mixed in, and wetted. A tracked vehicle was used to pack the courses. The surface of the courses was permitted to weather naturally. Finally, an M151 1/4-ton and an M35A1 2-1/2-ton truck with known vibrational response over similar natural terrain were used in turning the courses to natural cross-country random roughness. The soil type of the courses was lean clay (CL-ML), as classified by the Unified Soil Classification System (USCS). Test course 8 established in this same area was graded to provide the smoothest course. Course 9 was selected in natural terrain in the same area as courses 1, 2, and 4. The ground surface of course 9 was naturally weathered and considered to be realistic cross-country terrain.

8. Surface profiles were measured for each course with a survey rod and level, elevations being taken at intervals of 1 ft for the total length of each course. These profile data were detrended to remove the effects of profile slope and wavelength components greater than 60 ft. Surface roughness values of the detrended profile were developed in terms of rms elevation* for each course. Elevation profiles depicting courses

---

* Root-mean-square (rms) elevation in inches is the measure of terrain surface roughness characterized by the WES for a ride vibration criterion.

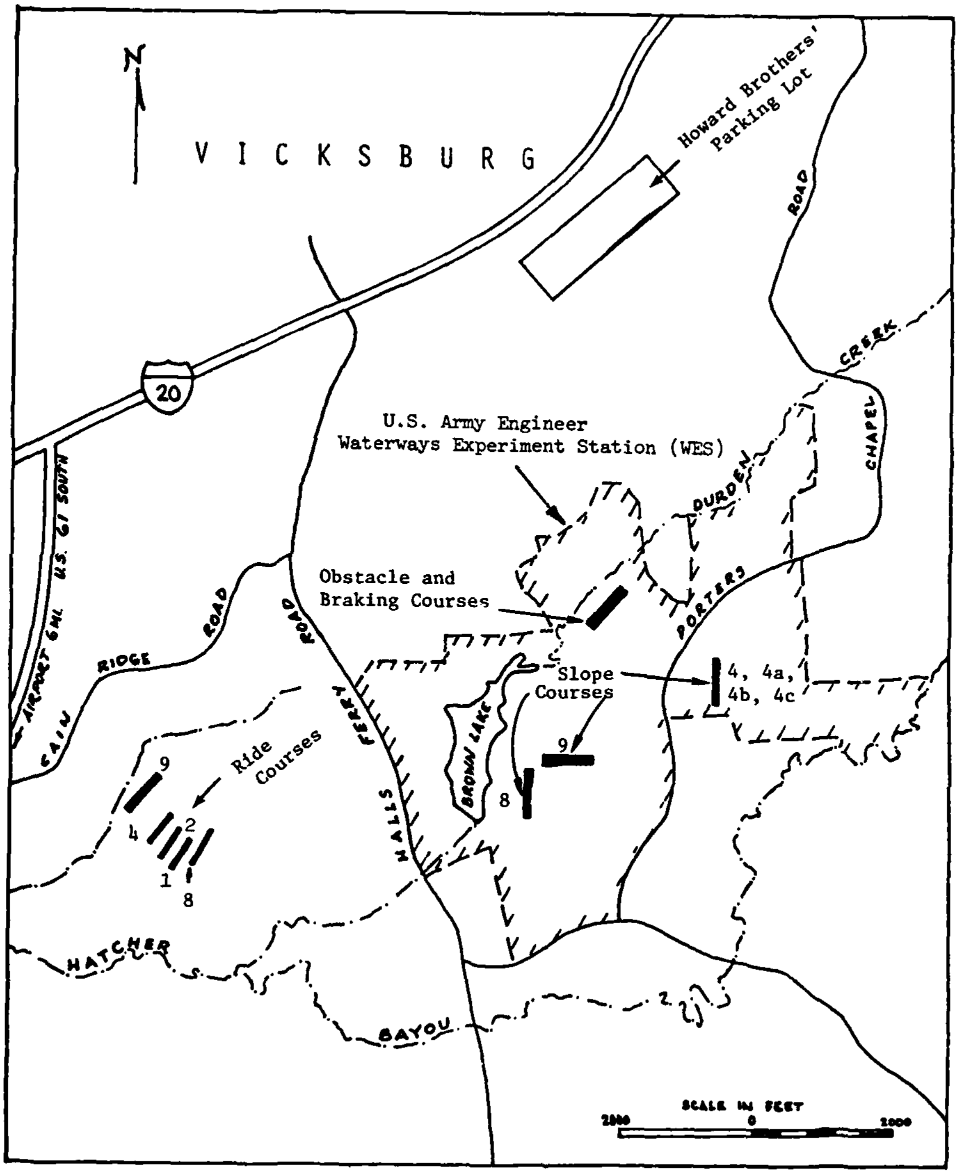
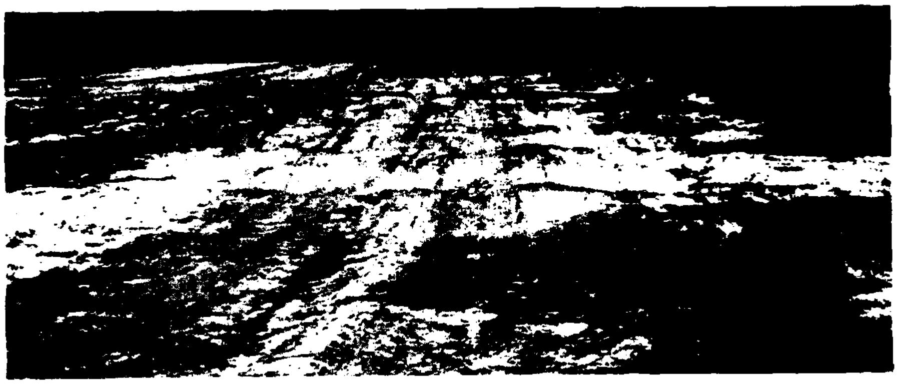


Figure 2. Location of test courses on and near WES at Vicksburg, Miss.

a. Course 1



b. Course 2

c. Course 4

Figure 3. Ride test courses (Continued)

d. Course 8

e. Course 9

Figure 3. (Concluded)

1, 2, and 9 are shown in Plates 1, 2, and 3, respectively. The test courses are identified as follows:

Test Course	Surface Roughness (rms), in.	Length, ft
1	2.62	300
2	1.55	300
4	0.69	300
8	0.28	300
9	0.61	300

Shock tests

9. A flat, level asphalt road at the WES was used for conducting vehicle shock tests to develop shock-limiting speed relations. Rigid, semicircular obstacles, 5.5, 8, and 10 in. high, were positioned along the road. The 5.5-in. obstacle is shown under the vehicle in Figure 1. An approach lane to each obstacle was established to permit the test vehicle to achieve the desired speeds. A stake was placed at a distance of 100 ft from the obstacles, and this distance was used with stopwatch times to compute vehicle speed upon contacting the obstacle.

Side slope tests

10. The side slope tests were conducted at various locations on the WES reservation. Views of test courses 4, 4a, 4b, 4c, and 9 are shown in Figures 4 and 5. A summary of the measured cone index data along with a general description of surface conditions are shown in Table 2. All slope courses were on well-drained grass-covered surfaces. The slopes were relatively firm, but substantial rainfall had occurred two days prior to testing and wet spots were still present on slope 4c as indicated in Table 2. For safety reasons the configuration of the test vehicle was altered for the slope tests by removal of a portion of the simulator mass. This was compensated for by the addition of outriggers to prevent vehicle overturning. No weight or center of gravity change resulted from this alternate test configuration.

Turning and braking tests

11. The turning tests were conducted on the asphalt runway at the Vicksburg Municipal Airport and on the Howard Brothers' asphalt parking lot. The Vicksburg Municipal Airport is located approximately 6 miles

Figure 4. View of slopes 4, 4a, 4b, and 4c

Figure 5. View of slope 9

south of Vicksburg on U. S. Highway 61, and the Howard Brothers' parking lot is located on the south side of U. S. Interstate 20 near the WES. The braking tests were conducted at the Vicksburg Municipal Airport and on the WES reservation.

Instrumentation Measuring Vehicle Dynamics Responses

12. The sensors and their locations used in providing vehicle response data in the tests conducted in this study are shown in Table 3. Fifteen accelerometers, five stain gages, and one gyro were monitored in the tests.

Ride tests

13. In the ride tests, sensors 1-10, 21, and 22 (see Table 3) were connected to an FM magnetic tape recorder which was shock-mounted and secured on board the test vehicle. Sensors 1, 5, and 8 were also connected to a WES portable ride meter. The ride meter converted these acceleration signals and displayed absorbed power (a measure of ride severity). At the end of each test, the values of total absorbed power and elapsed test time were obtained from the ride meter display. In addition, tests were conducted on course 1 with sensors 9 and 10 disconnected and sensors 16-19 connected.

Shock tests

14. Instrumentation sensors recorded during the shock (vehicle obstacle-impact) tests were 4-8, 15-19, 21, and 22. A meter designed to indicate the peak acceleration in gravities was also connected to sensor 4 so each test could be monitored instantly.

Side slope tests

15. In the side slope tests, sensors 1, 4-8, 11-14, 16, and 19-22 were connected to the FM recorder and activated.

Test Procedures

Ride tests

16. Several tests were conducted with the test vehicle over each ride course at selected test speeds ranging from a low of about 5 mph, increased usually in 3- to 5-mph increments until the test director determined that sufficient test data had been developed for each course.

17. Each test began with the vehicle positioned a sufficient distance from the beginning of the test course to enable the driver to reach the desired test speed before entering the test course. This speed was then maintained as constant as possible (using the vehicle's speedometer) throughout the length of the course. An observer rode in the vehicle during each test, selected the test speed, operated the ride meter, and narrated details of the test onto magnetic tape. At the end of each test, the average absorbed power and average speed were calculated from elapsed time, total vertical absorbed power (obtained from the ride meter), and the length of the test course. This procedure provided on-the-spot indications of average absorbed power versus speed for use by field personnel in planning the sequence of the tests to ensure that sufficient tests were conducted to develop the necessary relations.

Shock tests

18. Several tests were conducted over each obstacle (i.e., 5.5-, 8-, and 10-in. heights) at relatively constant speeds from 3.5 mph to the maximum safe speed to characterize the vehicle shock response. In the standard test both the left and right running gear of the vehicle struck the obstacle simultaneously.

19. Each test began by positioning the test vehicle a sufficient distance from the timing stake so the driver could reach the desired test speed before reaching the stakes. He then attempted to maintain that speed (using the vehicle's speedometer) until the vehicle had completely crossed the obstacle. Acceleration was measured and displayed on a meter designed to indicate the peak acceleration in gravity units (g's) and obstacle-impact speed was computed from the distance and elapsed time

between the time stake and obstacle contact. Once again this procedure provided on-the-spot measurements of acceleration versus speed over each obstacle for use by field personnel in planning the test sequence to ensure that sufficient tests were conducted to develop the necessary relations.

Side slope tests

20. Prior to testing, various test courses, each with constant side slope, were staked out and elevation profiles and cross sections were taken to determine each course's slope. The vehicle negotiated each test course at a constant speed. The time required to negotiate the test course along with the test course length were used to calculate vehicle speed. The first pass was conducted at approximately 5 mph and subsequent passes were conducted at increasing 5-mph increments until the maximum safe speed was attained or the maximum speed the vehicle could attain with the available approach was reached. Any irregularities occurring during the test were noted and recorded by the test engineer and test driver.

Turning tests

21. Prior to testing, pylons were used to lay out a one-quarter circle on three prescribed vehicle center-line radii: 60, 107, and 200 ft, and an approach speed trap (usually 100 ft in length) for each radius. The vehicle negotiated the test course at a constant speed. The time required to negotiate the speed trap along with trap length were used to calculate the speed entering the turn. The time required to negotiate the turn along with the length of the turn were used to calculate the speed at which the vehicle negotiated the turn. The first run was conducted at approximately 5 mph and subsequent runs were conducted at increasing increments until the maximum safe speed was attained or the maximum speed the vehicle could attain with the available approach was reached. Any irregularities occurring during the test were noted and recorded by the test engineer and test driver.

Braking tests

22. Prior to testing, a speed trap (usually 100 ft in length) was staked out. The vehicle entered the speed trap at a constant speed.

At the end of the speed trap the driver applied the brakes as quickly as possible. The time required to negotiate the speed trap along with trap length were used to calculate vehicle speed. The time and distance required for the vehicle to stop were used to calculate deceleration rate. The first run was conducted at approximately 5 mph and subsequent runs were conducted at increasing 5-mph increments until the maximum safe speed was attained or the maximum speed the vehicle could attain with the available approach was reached. Any irregularities occurring during the test were noted and recorded by the test engineer and test driver.

PART III: ANALYSIS OF TEST DATA

Dynamic Test Results

23. The basic data from the ride tests are listed in Table 4, and the basic obstacle-impact data were tabulated as shown in Table 5. Table 6 presents a summary of vehicle drivers' comments. Other vehicle response data measured but not presented in this report have been provided to and will be analyzed by Boeing to determine vehicle structural performance.

Ride tests

24. Ride quality over continuous terrain is presently quantified as absorbed power at the driver's seat and is used as a basis for assessing the speeds at which a driver will operate his vehicle. Absorbed power, which is derived from acceleration measurements, is the rate at which vibrational energy is absorbed by a human. Absorbed power as a ride severity criterion was established through laboratory tests at the U. S. Army Tank-Automotive Command (TACOM) several years ago. Six watts of absorbed power was established as a reasonable standard human tolerance limit when vibration was in the vertical direction only. While results of field tests indicate that a driver will often subject himself to 10-15 w for short periods of time, he will not willingly subject himself to more than 6 w for prolonged periods of time; extreme fatigue could result from higher exposure. Tests with numerous wheeled and tracked vehicles indicate that the absorbed power in the vertical direction (AP_{vt}) at the driver's seat best agrees with the driver's opinion of ride quality and generally appears to be the most critical factor in determining ride performance. Six watts of AP_{vt} at the driver's seat is the measure of ride quality presently used in assessing the speeds at which a driver will operate a vehicle. Absorbed power for fore-and-aft and side-to-side directions were measured for research purposes but are not presented in this report.

Ride test results

25. Plates 4-8 show the AP_{vt} versus speed for each test course. In tests on courses 1 and 2, the maximum vehicle speed was determined

by driver ride tolerance. The maximum speed on courses 4, 8, and 9 was limited by the available approach distance; the vehicle could not be accelerated to speeds higher than those shown. However, on course 8, observations made during testing indicated that driver's ride would not limit vehicle speed. The speeds at 6 w AP_{vt} from the curves in Plates 4-8 were plotted versus surface roughness and are shown in Plate 9. In Plate 9, a faired curve through the data points shows how ride-limiting 6-w speed at the driver's seat changes with surface roughness. As indicated by the closed symbol data point on Plate 9, a measured 6-w AP_{vt} speed value was not attained on course 8 due to low surface roughness. However, this data point contributes significantly in establishing the performance curves.

26. The ride performance curve shown in Plate 9 is essentially the same as the performance curve established for a standard M813A1 carrying a 5-ton payload which was tested in a study conducted at Fort Knox, Ky., in 1977. The M813A1 is equipped with 9:00X20 tires while the M812A1 proposed ROLAND vehicle had 11:00X20 tires. The M813A1's wheelbase was 36.0 in. shorter and the M813A1 weighed 18,159 lb less than the M812A1 ROLAND vehicle.

27. Test results showing ride response at the commander's station and center of gravity position are shown in Plates 10-19. Plates 20-24 show composite plots of AP_{vt} versus speed for the three locations for each test course. The following tabulation shows the 6-w AP_{vt} vehicle speed on the driver's seat and the corresponding AP_{vt} at the center of gravity and at the commander's station:

			AP_{vt}, watts		
Test Course	rms	Vehicle Speed mph	On the Driver's Seat	At the Center of Gravity	At the Commander's Station
1	2.62	6.8	6.0	3.5	9.0
2	1.55	9.0	6.0	3.5	9.5
4	0.69	10.8	6.0	3.8	7.0
8	0.28	24.8	3.5	1.0	1.0
9	0.61	15.3	6.0	2.0	2.7

The data indicate that when the driver is riding at his 6-w limit, the ride at the center of gravity is very good (as it should be) and the ride at the commander's station is tolerable, although a ride at about 9 w (note test courses 1 and 2) can become uncomfortable if a person is subjected to it for a long period of time. The AP_{vt} at the commander's station in the tabulation for courses 2 and 4 can be a little misleading (see Plates 21 and 22) in that the values shown are very close to the maximum AP_{vt} measured at this location. At slightly higher speeds the commander's ride began to improve.

Shock tests

28. The ability of a vehicle to negotiate minor abrupt discrete obstacles is an important aspect of vehicle ground mobility. Logs, small ditches, boulders, rice paddy dikes, etc., are encountered frequently in off-road travel and produce speed-controlling shock loads that depend on the sizes of the obstacle and the traction element, as well as the speed at which the obstacle is impacted. Results of past studies have indicated that obstacle height is a suitable first-order descriptor for characterizing such discrete obstacles. The response criterion currently used for limiting vehicle speed is that level at which the driver's station vertical acceleration (measured on the floor under the driver's seat) reaches 2.5 g's (with the acceleration peak duration determined by passing the signal through a 30-Hz filter) when the left and right vehicle running gear strike an obstacle simultaneously. This response criterion is the standard used in the AMM for the prediction of vehicle performance over discrete obstacles.

29. The obstacle-crossing ability of the test vehicle, the speed in miles per hour, and the peak vertical acceleration as the vehicle crossed 5.5-, 8-, and 10-in.-high obstacles are shown in Table 5. Figure 6 shows the test vehicle airborne during test No. 77 in which a peak acceleration of 2.8 g's at the driver's station was recorded. For each obstacle, acceleration was plotted versus speed, and curves were faired through the data points. The relations for the driver's station are shown in Plate 25.

Figure 6. ROLAND Wheeled Vehicle airborne on obstacle test No. 77

30. The test speed from Plate 25 at which the peak acceleration reached the 2.5-g level was plotted versus obstacle height and curves were faired through the data points. The obstacle height versus speed relation for the ROLAND vehicle is shown in Plate 26; also shown on Plate 26 are the performance curves for the M813A1. In general, this performance relation for the test vehicle is slightly better than the shock characteristics of the M813A1.

31. Test results showing obstacle-impact response at the commander's station is shown in Plate 27 (test data shown in Table 5) and the shock performance is shown in Plate 28. A comparison of Plates 26 and 28 indicates that the ROLAND vehicle commander receives a lesser shock than does the driver on the 5.5- and 8-in. obstacles. However, on the 10-in. obstacle the commander is subjected to a more severe shock than the driver.

32. In addition to the test to determine the performance relations discussed in the previous paragraph, a few tests were conducted where

only the left wheel of the test vehicle struck the obstacle. These few tests were conducted on both a level course and on a course with a side slope of 21.7 to 23.1 percent. The test data are shown in Table 5, tests 95-122, and Table 7, course 9, passes 6-9.

33. On the level course, the vehicle speed, acceleration data, and driver's comments, as expected, indicate that the shock generated when only one side of the vehicle strikes an obstacle is somewhat less than that when the wheels on both sides of the vehicle strike an obstacle simultaneously. Comments from personnel observing these tests indicate that the vehicle appeared to be relatively stable and was not likely to turn over crossing obstacles such as these.

34. Obstacles were superimposed on side slope course No. 9 and a number of tests were conducted. Although test data are limited, the measured acceleration results are consistent with the results of the tests conducted on a level surface. However, results of observations indicate that control and instability problems were developing. These results are discussed in more detail in paragraphs 38 and 40.

Side Slope Tests

35. A summary of the measured slope data is presented in Tables 2 and 7. Eleven tests were conducted on a range of slopes at various speeds. Also, one test was conducted at a safe speed with sinusoidal steering along the course. Five additional tests were conducted with obstacles superimposed on the slope. In two tests, a 5.5-in. obstacle was placed on the uphill half of the slope in such a manner that only the left wheels of the vehicle struck it. Likewise, two tests were conducted with an 8-in. obstacle on the uphill half of the slope. One additional test was run with a set of 8-in. obstacles across the slope so that both the left and right wheels would cross the obstacle simultaneously.

36. The maximum speeds the vehicle achieved on the slopes were controlled by approach length rather than by instability. Tests on the 4.5-percent slope at 16.0 mph indicated no instability problems and it

is fair to assume that the maximum safe speed on a 4.5-percent slope is probably the maximum speed the vehicle can achieve. On a 20.4-percent slope at 11.6 mph, no instability problems were noticed; however, it is believed that the safe speed is much less than the maximum speed of the vehicle. One NOGO occurred during testing on slope 4C on a 23.5-percent slope. The vehicle hit a wet spot and slid about 10 in. down the slope out of control before it was stopped. Figure 7 shows the test vehicle after it slid down the slope and stopped. Although the slope test data shown in Tables 2 and 7 are insufficient to allow a specific delineation of GO and NOGO based on slope, cone index, and surface condition, it appears that slopes greater than about 20 percent with a surface condition described as wet and surface cone index* less than about 75 cannot be negotiated by the test vehicle. Tests on the dry 24.7-, 26.2-, and 30.1-percent slopes at approximately 5 mph indicated no instability problems. Figure 8 shows the test vehicle negotiating the 30.1-percent slope at approximately 5 mph. Although no instability problems were noted, from observations it is believed that the maximum safe operating speed on a 30-percent slope is much less than the maximum speed of the vehicle.

37. An attempt was made to steer a sinusoidal path on the 21.7-percent side slope (course 9) at 6.4 mph. However a sinusoidal path could not be achieved because the vehicle could not be steered up slope out of the ruts previously made by the test vehicle in straight-line tests. The vehicle had no stability problems but it could not complete a sinusoidal path on the slope because of the ruts.

38. Tests on the single 5.5-in. obstacle on the 22.4-percent slope indicated no instability or control problems at a speed of 11.0 mph. This was the maximum speed the vehicle could attain due to approach distance.

39. During tests when the left wheels only crossed an 8-in. obstacle on the 22.8-percent slope (vehicle speed of 6.2 mph), the front end

---

* Cone index is an index derived from the resistance of soil to penetration that can be related to vehicle performance (Department of the Army Technical Manual TM 5-330, Chapter 9, Sep 68.)

Figure 7. View of the ROLAND Wheeled Vehicle after it slid down the 23.5-percent slope and stopped (Note outriggers were installed for safety purposes.)

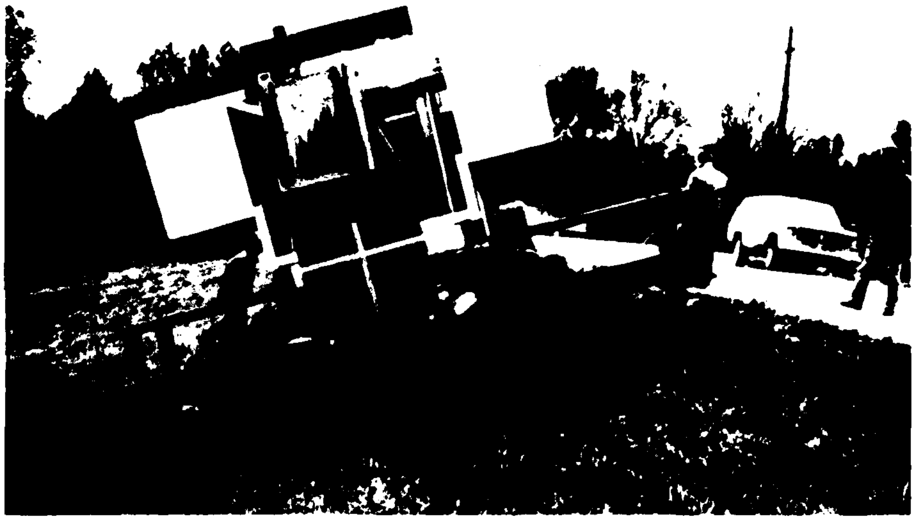


Figure 8. View of the ROLAND Wheeled Vehicle negotiating a 30.1-percent slope at a speed of approximately 5 mph (safety skids were never in contact with the ground)

Figure 9. View of the ROLAND Wheeled Vehicle negotiating a 22.8-percent slope with an 8-in. obstacle superimposed on the uphill half of the slope

of the vehicle slipped downslope as it passed over the obstacle. Figure 9 shows the test vehicle negotiating the 22.8-percent slope with the 8-in. obstacle superimposed on the uphill half of the slope. At the higher speed of 11.1 mph, although there appeared to be no instability problems, the front wheels of the vehicle came off the ground and slipped several inches down the slope, indicating the vehicle was out of control for an instant. Although the test driver indicated he experienced no control problems, observation of these tests indicated that the maximum safe speed in this case over an 8-in. obstacle on a 23-percent slope appears to be approximately 6 mph.

40. During test No. 123 on the two 8-in. obstacles on the 23.5-percent slope at 6.1 mph where both the left and right wheels struck the obstacle simultaneously, the vehicle's front wheels were airborne and slipped downslope about 9 in. The vehicle was out of control while airborne and an instability problems appeared to be developing. The maximum speed over the 8-in. obstacles on a 23.5-percent slope should be the vehicle's creep speed (2 or 3 mph).

Turning Tests

41. Turn tests were conducted on three prescribed radii: 60, 107, and 200 ft. A summary of the measured data is presented in Table 8. The tests on the 107-ft radius were conducted on the asphalt surface at the Vicksburg Municipal Airport. A view of the vehicle negotiating the 107-ft turning radius is shown in Figure 10. The other tests were conducted on the asphalt surface of the Howard Brothers' parking lot. The maximum safe speeds recommended by Boeing Aerospace Company (see Figure A1) for the three radii were 16, 20, and 30 mph, respectively. However, due to the unavailability of a long approach, the maximum speed attained on each radius was 11.9, 18.2, and 23.8 mph, respectively. A comparison of vehicle speed to turning radius is shown in Plate 29. Also shown in this plate is the calculated maximum safe speed versus turning radius. No instability problems were noted by the test engineer or the test driver.

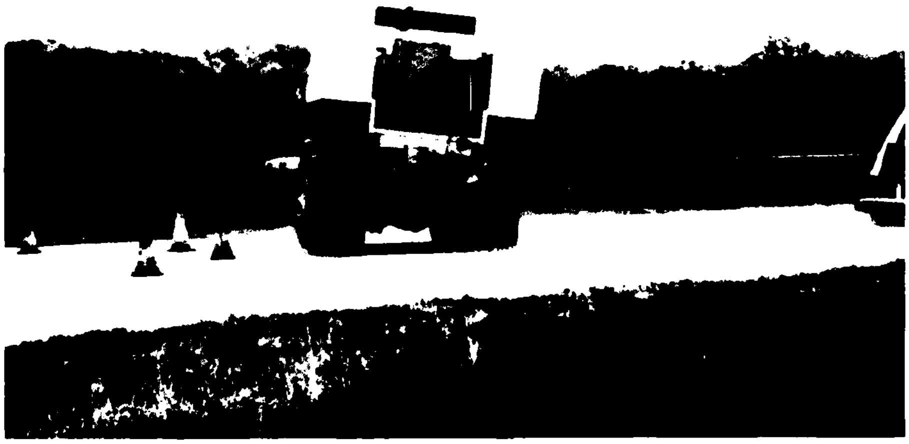


Figure 10. View of the ROLAND Wheeled Vehicle negotiating the 107-ft turning radius at 18.2 mph

Braking Tests

42. Using the previously described test procedures, braking tests were conducted at the Vicksburg Municipal Airport on a damp asphalt surface and at the WES on a dry asphalt surface. The brakes on the vehicle were tested in an as-received condition following approximately 7 years of storage, without any rework. The results of these tests are summarized in Table 9. One test driver drove all the tests at the Vicksburg Municipal Airport and two drivers drove the tests conducted at the WES. The two drivers were used to get an indication of driver effects. In all of these tests, the vehicle was braked to a stop without skidding. Plate 30 shows how the original M812A1 brake system performed when ROLAND modifications were made to the vehicle. As seen in Table 9 and Plate 30, the distance required to stop was much less on the dry surface than on the damp surface, especially at the higher speeds. No instability problems were noted by the test engineer or the test drivers. Plate 30 indicates there was very little difference in stopping distance for the two drivers. This indicates the drivers' reaction times were about the same. These limited test data also indicate that the brake system appears to be adequate for the test vehicle; however, fade performance was not included in these tests.

Drivers' and Test Director's Observations

43. During this test program observations were solicited from the test personnel to answer some specific questions. The questions and answers are presented in Table 10. One significant event occurred during driver familiarization prior to the start of testing. While practice driving on a gravel road on top of a levee, a Boeing driver drove the test vehicle too far to the left side and ran off onto the side of a levee (see Figure 11). The left side of the vehicle was on a soft soil (0-6 CI = 50) and the right side was on the firm levee (0-6 CI > 750+). The rear of the vehicle tilted approximately 20 deg to the left. The test drivers and test director felt the vehicle might have turned over if the rear bogies had not bottomed on the firm levee.

a. Front view

b. Rear view

Figure 11. Views of the ROLAND test vehicle after the driver ran off the levee

PART IV: SUMMARY OF FIELD TEST RESULTS

44. Based on the results of the test data presented in Part III, the following summary of test results is presented:

a. The ride performance of the proposed M812A1 ROLAND Wheeled Vehicle is the same as the ride performance of the standard M813A1 (Plate 9).

b. The ride comfort at the commander's seat is slightly more than the ride comfort at the driver's seat for the ROLAND Wheeled Vehicle (Plates 20-24).

c. The ROLAND Wheeled Vehicle's obstacle-crossing performance in terms of shock performance over single obstacles is slightly better than the standard M813A1 (Plate 26).

d. The shock received at the commander's station as the vehicle crosses an obstacle is less than that received at the driver's station for obstacles 8 in. or lower; however, on obstacles of 10 in. the commander receives more shock than does the driver (Plates 25-28).

e. The ROLAND Wheeled Vehicle can operate on dry off-road side slopes up to 30-percent slopes (30-percent slope was the steepest slope tested) at reduced speed (paragraphs 35 and 36).

f. Test results show that the test vehicle will encounter control problems on wet side slopes when the slope is greater than 20 percent and surface cone index is less than about 75 (paragraph 36).

g. When obstacles are superimposed on side slopes (16.6- to 23.5-percent slopes), control and stability problems can develop even at low speeds (Table 7).

h. Test results tend to verify the calculated maximum safe speed versus turning radius relation (Plate 29).

i. Limited test data indicate that the brake system appears to be adequate for stopping the proposed ROLAND Wheeled Vehicle; however, fade performance was not included in these tests (Plate 30).

Table 1

General Characteristics of ROLAND Wheeled Vehicle

Gross vehicle weight, lb	50,239
Power-to-weight ratio, hp/ton	9.96
Wheelbase, in.	215
Minimum ground clearance, in.	10.25
Approach angle, deg*	46
Departure angle, deg**	29
Vehicle cone index for one pass (VCI_1)†	
Fine-grained soils	56
Coarse-grained soils††	54
Maximum speed, mph	52
Vertical CG height of total mass from ground, in.	70.5

Engine: Model NHC-250, 6-cylinder in-line diesel; 240 gross horsepower at 2100 rpm; 690 ft-lb gross torque at 1500 rpm; governed speed 2140 rpm at full load.

Transmission: Manual - 5 speeds forward, 1 reverse. Ratios: 1st 6.07:1; 2nd 3.4:1; 3rd 1.79:1; 4th 1.00:1; 5th 0.78:1; rev 6.09:1

Transfer Case: 2 speed, automatic overrunning front axle drive control. Ratios: front - high 1.07:1, low 2.16:1 rear - high 1.00:1, low 2.02:1

(Continued)

* Angle formed by a line tangent to a point on the first tractive element (tires or tracks) and a point on the leading edge of vehicle and the ground surface.

** Angle formed by a line tangent to a point on the rear tractive element (tire or track) and a point on rear edge of vehicle and the ground surface.

† Vehicle cone index for one pass (VCI_1) is the minimum soil strength required for a vehicle to make one pass. The VCI_1 is relatable to soil strength obtained from cone penetrometer measurements. The cone penetrometer measurements are derived from the resistance of the soil to penetration of a 30-deg cone of 0.5-sq-in. base projected area at a penetration speed of 6 ft/min.

†† Sand VCI based on 25-percent tire deflection.

Table 1 (Concluded)

Axles: Type - hypoid, single speed, double reduction; Ratio: 6.443:1, 3000 ft-lb torque rating

Springs: Front - semielliptical, 12 leaves, 2271 lb/in. rate; Rear - semielliptical, inverted, 15 leaves, 5911 lb/in. rate

Wheels: Offset dist: 20 in. diam x 8.5 in. wide; 7-1/8-in. offset

Tires: Size - 11:00x20, 14 ply; tread design - directional mud and snow; tire pressure,* psi - 75 (front), 55 (rear)

Steering: Hydraulic cam w/power assist.; 23.4:1 ratio

Brakes: Internal expanding drum, air over hydraulic; drum size: 16-1/2-in. diam x 5-1/2-in. wide; effective area: front 339 sq in.; rear 678 sq in.

* Sponsor's recommended inflation pressure (cross-country).

Table 2

Summary of Measured Terrain Data for Slope Tests

Slope No.	Slope percent*	Average Cone Index at Depths, in.** 0	1	2	3	4	Average Cone Index of Layers in. 0-3	Vegetation Coverage	Surface Condition	Remarks
4	24.7	127	187	221	300+	-	209+	Sparse	Damp	Maintained only when necessary
4A	30.1	99	150	185	300+	-	184+	Sparse	Damp	Maintained only when necessary
4B	26.2	119	171	189	300+	-	195+	Sparse	Damp	Maintained only when necessary
4C	23.6	52	97	124	164	300+	109	Moderate	Wet	Maintained only when necessary
8	4.5	89	157	218+	300+	-	191+	Heavy	Dry	Slope well maintained
9	16.6	75	96	123	150	242+	111	Heavy	Damp	Slope well maintained

* Slope prior to traffic.
** Cone index is an index derived from the resistance of soil to penetration that can be related to vehicle performance (Department of the Army Technical Manual TM 5-330, Chapter 9, Sep 68).

Table 3

Instrumentation for Measuring Vehicle Responses

	Sensor	Measurement	Location
1.	Accelerometer	Vertical acceleration	On the driver's seat
2.	Accelerometer	Fore-to-aft acceleration	On the driver's seat
3.	Accelerometer	Side-to-side acceleration	On the driver's seat
4.	Accelerometer	Vertical acceleration	On the floor under the driver's seat
5.	Accelerometer	Vertical acceleration	At the center of gravity*
6.	Accelerometer	Fore-to-aft acceleration	At the center of gravity*
7.	Accelerometer	Side-to-side acceleration	At the center of gravity*
8.	Accelerometer	Vertical acceleration	At the commander's seat
9.	Accelerometer	Fore-to-aft acceleration	At the commander's seat
10.	Accelerometer	Side-to-side acceleration	At the commander's seat
11.	Accelerometer	Vertical acceleration	On the right side of the vehicle frame above the front axle
12.	Accelerometer	Vertical acceleration	On the left side of the vehicle frame above the front axle
13.	Accelerometer	Vertical acceleration	On the right side of the vehicle frame above the center of the rear bogie
14.	Accelerometer	Vertical acceleration	On the left side of the vehicle frame above the center of the rear bogie
15.	Accelerometer	Vertical acceleration	On the left front axle
16.	Strain gage	Strain	On the right side at the bottom of the vehicle frame between the cab and payload**
17.	Strain gage	Strain	On the right side at the top of the vehicle frame between the cab and payload**

(Continued)

* Approximately at the center of gravity of the sprung mass. Actual accelerometers' locations: 49 in. along the longitudinal axis forward from the centerline of rear the bogie, 3.0 in. to the right from the centerline of the longitudinal axis, and 79.4 in. above the ground, respectively, for No. 5, 6, and 7.

** Location: 97.75 in. along a longitudinal axis forward from the centerline of the rear bogie.

Table 3 (Concluded)

Sensor	Measurement	Location
18. Strain gage	Strain	On the left side at the bottom of the vehicle frame between the cab and payload**
19. Strain gage	Strain	On the left side at the top of the vehicle frame between the cab and payload**
20. Gyro	Roll angle	Near the vehicle's center of gravity
21. Pushbutton	Event indicator for tape recording	--
22. Microphone	Voice for tape recording	--

Table 4

Results of Controlled Ride Tests of ROLAND Wheeled Vehicle

Test No.	Direction of Travel Station	Speed mph	Absorbed Power, Vertical Watts: On Driver's Seat	At the Center of Gravity	At the Commander's Station
			Test Course 4, Surface Roughness = 0.69 (rms), in.		
11	0-300	9.39	4.45	2.98	6.51
12	300-0	9.26	3.80	2.67	6.47
13	0-300	8.35	4.04	2.86	5.47
14	300-0	8.35	2.86	2.79	7.05
15	0-300	11.76	7.59	3.39	6.26
16	300-0	11.00	6.18	3.55	7.04
17	0-300	13.82	8.18	3.58	4.46
19	0-300	15.62	7.56	2.67	3.51
20	300-0	12.48	7.44	3.04	6.46
21	0-300	18.43	10.20	4.14	2.88
22	300-0	5.70	1.56	0.42	0.84
23	0-300	15.04	8.24	3.16	3.53
24	0-300	16.24	8.49	2.94	3.10
25	0-300	16.24	8.65	2.70	3.10
26	0-300	17.05	8.92	3.42	2.75
			Test Course 2, Surface Roughness = 1.55 (rms), in.		
27	0-300	5.76	1.66	0.37	0.68
28	300-0	5.86	1.83	0.43	1.12
29	0-300	9.09	5.91	3.29	9.16
30	300-0	9.05	5.58	3.19	9.56
31	0-300	12.04	11.88	4.24	8.65
32	300-0	11.69	9.71	4.23	10.11
33	0-300	10.28	7.74	3.92	9.80
34	300-0	6.84	2.31	1.17	3.55
			Test Course 1, Surface Roughness = 2.62 (rms), in.		
35	0-300	4.71	1.75	0.58	1.50
36	300-0	4.80	1.88	0.70	1.71
37	0-300	8.93	22.70	8.12	18.34
38	300-0	8.32	14.80	5.28	14.27
39	0-300	7.41	10.54	5.43	15.43
40	300-0	6.73	5.92	3.49	8.72

(Continued)

NOTE: Missing test numbers (1 through 10) represent tests in which the instrument malfunctioned.

Table 4 (Concluded)

Test No.	Direction of Travel Station	Speed mph	Absorbed Power, Vertical Watts: On Driver's Seat	At the Center of Gravity	At the Commander's Station
	Test Course 8, Surface Roughness = 0.28 (rms), in.				
41	0-300	9.93	2.14	1.07	3.20
42	300-0	9.84	2.55	1.20	3.41
43	0-300	19.12	3.08	0.84	2.90
44	300-0	11.83	2.89	1.04	3.12
45	0-300	23.25	2.84	1.14	1.93
46	300-0	14.41	1.83	0.56	1.06
47	0-300	24.65	3.49	1.08	1.08
	Test Course 9, Surface Roughness = 0.61 (rms), in.				
49	300-0	8.30	5.18	0.84	4.98
52	0-300	12.04	5.53	2.47	5.00
53	300-0	11.63	5.80	3.13	6.59
54	0-300	17.79	7.83	2.35	2.70
55	300-0	13.12	5.58	2.31	4.42
56	0-300	18.60	8.27	2.18	3.73
57	0-300	14.83	5.80	2.03	3.04
58	300-0	6.60	1.94	0.74	2.10
59	0-300	14.51	5.18	1.70	2.84
60	300-0	5.31	1.69	0.47	1.35
61	0-300	16.24	6.59	2.22	2.30

Table 5

Results of Obstacle Shock Test of ROLAND Wheeled Vehicle

Test No.	Obstacle Height in.	Speed mph	Maximum Peak Acceleration, g's: Driver's Seat	Maximum Peak Acceleration, g's: Commander's Station	Side Slope %	Remarks
62	5.5	5.4	1.4	1.5	0	Right and left wheel struck the obstacle simultaneously
63	5.5	10.2	1.7	-	0	"
68	5.5	11.7	1.7	1.05	0	"
69	5.5	10.7	1.8	1.2	0	"
70	5.5	18.2	1.7	1.05	0	"
71	5.5	12.6	1.9	1.05	0	"
72	5.5	24.4	1.8	1.2	0	"
73	5.5	16.1	1.6	0.9	0	"
74	5.5	28.4	2.0	1.05	0	"
75	8.0	4.4	1.8	0.9	0	"
76	8.0	8.0	2.1	2.4	0	"
77	8.0	10.1	2.8	1.95	0	"
78	8.0	9.0	2.7	-	0	"
79	8.0	8.2	2.4	2.4	0	"
81	10.0	6.8	2.6	-	0	"
92	10.0	4.1	2.1	2.1	0	"
93	10.0	4.9	2.3	-	0	"
94	10.0	4.1	-	3.0	0	"
95	10.0	3.8	0.9	-	0	Only the left wheel
96	10.0	6.2	1.7	-	0	struck the obstacle
99	8.0	9.7	1.9	-	0	" "
100	8.0	13.6	2.1	-	0	"
101	8.0	18.0	2.1	-	0	"
102	5.5	28.6	1.4	-	0	"
119	5.5	5.8	0.8	-	22.1	"
120	5.5	11.0	2.0	-	22.4	"
121	8.0	6.2	1.4	-	22.8	"
122	8.0	11.1	1.7	-	23.1	"
123	10.0	6.1	1.6	-	23.5	Right and left wheel struck the obstacle simultaneously

* Acceleration measured on the floor under the driver's seat.

NOTE: Missing test numbers were tests in which instrument malfunctioned.

Table 6

Drivers' Comments

Background: Messrs. Carl R. May and David E. Strong were the test drivers for this test program. Both drivers have at least 10 years' experience driving standard military tracked and wheeled vehicles along with various experimental tracked and wheeled concept vehicles and test beds. Both men have been cited on numerous test programs for their professionalism and expert ability in driving the various vehicles. Below is a list of pertinent questions along with the composite answers given by the drivers after tests were completed:

1. Did you have any feeling of instability of the vehicle?

No vehicle instability was felt during testing; however, during drivers' training in the incident where the Boeing driver ran off the levee (see Paragraph 43) Mr. May, who was a passenger, felt that the vehicle could have turned over if the rear bogies had not bottomed out on the hard levee.

2. Were you concerned about personal safety?

At no time during testing did we feel our personal safety was in danger.

3. How did this system drive with respect to other wheeled systems you have driven?

The test vehicle handles roughly like a 2-1/2-ton M35 carrying an M151 jeep in the cargo area. The vehicle sways in curves but does not give you a feeling of instability.

4. Did you feel the system is underpowered or acceptable?

The vehicle has sufficient power in first and second gears; however, the vehicle seems to lose much of its power in third and fourth gears--indicating insufficient power.

5. Was visibility a problem (e.g., rear view mirrors)?

Visibility was not a problem during any of the testing. The adjustable rear view mirror worked exceptionally well.

Table 7

Results of Slope Tests of ROLAND Wheeled Vehicle

Slope No.	Pass No.	Slope Percent	Effective Slope with Obstacle	Obstacle Height in.	Speed mph	Performance	Observer's Comments	Drivers' Comments
4	1	24.7	NA	NA	5.2	GO	Vehicle stable	No problems
4A	1	30.1	NA	NA	4.9	GO	Vehicle stable	No problems
4B	1	26.2	NA	NA	5.4	GO	Vehicle stable	No problems
4C	1	23.6	NA	NA	4.6	NOGO	Slid off due to soft spot	Hit wet spot
8	1	4.5	NA	NA	7.0	GO	Vehicle stable	No problems
8	2	4.5	NA	NA	11.0	GO	Vehicle stable	No problems
8	3	4.5	NA	NA	16.0	GO	Speed limited by approach	No problems
9	1	16.6*	NA	NA	4.6	GO	Vehicle stable	No problems
9	2	17.9*	NA	NA	6.6	GO	Vehicle stable	No problems
9	3	19.2*	NA	NA	11.4	GO	Vehicle stable	No problems
9	4	20.4*	NA	NA	11.6	GO	Speed limited by approach	No problems
9	5	21.7*	NA	NA	6.4	GO	Could not get out of ruts	Could not get out of ruts
9	6	22.1*	29.0	1-5.5**	5.8	GO	No control problems	No control problems
9	7	22.4*	29.3	1-5.5**	11.0	GO	No control problems	No control problems

(Continued)

* The percent slope increased due to rutting. It was assumed that the rutting increased linearly with the number of passes.

** One obstacle was stationed on the uphill half of the slope so that only the left wheel of the test vehicle struck the obstacle.

Table 7 (Concluded)

Slope No.	Pass No.	Slope Percent	Effective Slope with Obstacle	Obstacle Height in.	Speed mph	Performance	Observer's Comments	Drivers' Comments
9	8	22.8*	32.9	1-8**	6.2	GO	Appeared slightly out of control	No control problems
9	9	23.1*	32.9	1-8**	11.1	GO	Front of vehicle jumped slightly downhill	No control problems
9	10	23.5*	23.5	2-8+	6.1	GO	Vehicle jumped about 9 in. downhill, appeared out of control	Momentary control problems

+ Two obstacles were stationed end to end on the slope so that both the left and right wheels would strike the obstacles at the same time.

Table 8

Results of Turning Tests with ROLAND Wheeled Vehicle

Test No.	Area	Speed Entering Turn, mph	Average Speed Negotiating Turn, mph	Average Slope Percent	Observer's Comments	Drivers' Comments
		60-ft Turning Radius, Driver: Strong				
1	Howard Brothers' parking lot	4.6	6.1	-1.6*	Safe, stable	No problem
2	Howard Brothers' parking lot	7.0	6.7	-1.6	Safe, stable	No problem
3	Howard Brothers' parking lot	9.0	8.6	-1.6	Safe, stable	No problem
4	Howard Brothers' parking lot	9.7	9.7	-1.6	Safe, stable	No problem
5	Howard Brothers'	13.1	11.9	-1.6	Safe, stable	No problem
		107-ft Turning Radius, Driver: May				
1	Vicksburg Airport	4.9	5.3	0.5	Safe, stable	No problem
2	Vicksburg Airport	6.8	7.4	0.5	Safe, stable	No problem
3	Vicksburg Airport	9.6	9.5	0.5	Safe, stable	No problem
4	Vicksburg Airport	10.8	11.6	0.5	Safe, stable	No problem
5	Vicksburg Airport	13.4	14.1	0.5	Safe, stable	No problem
6	Vicksburg Airport	17.0	16.4	0.5	Safe, stable	No problem
7	Vicksburg Airport	20.1	18.2	0.5	Safe, stable	No problem

(Continued)

* Minus sign (-) indicates the area elapsed away from the center of the circle.

Table 8 (Concluded)

Test No.	Area	Speed Entering Turn, mph	Average Speed Negotiating Turn, mph	Average Slope Percent	Observer's Comments	Drivers' Comments
			200-ft Turning Radius			
1	Howard Brothers' parking lot	7.6	7.9	0.8	Safe, stable	No problem
2	Howard Brothers' parking lot	11.3	12.0	0.8	Safe, stable	No problem
3	Howard Brothers parking lot	16.2	16.2	0.8	Safe, stable	No problem
4	Howard Brothers' parking lot	20.6	19.1	0.8	Safe, stable	No problem
5	Howard Brothers' parking lot	21.3	23.8	0.8	Safe, stable	No problem

Table 9

Results of Braking Tests with ROLAND Wheeled Vehicle

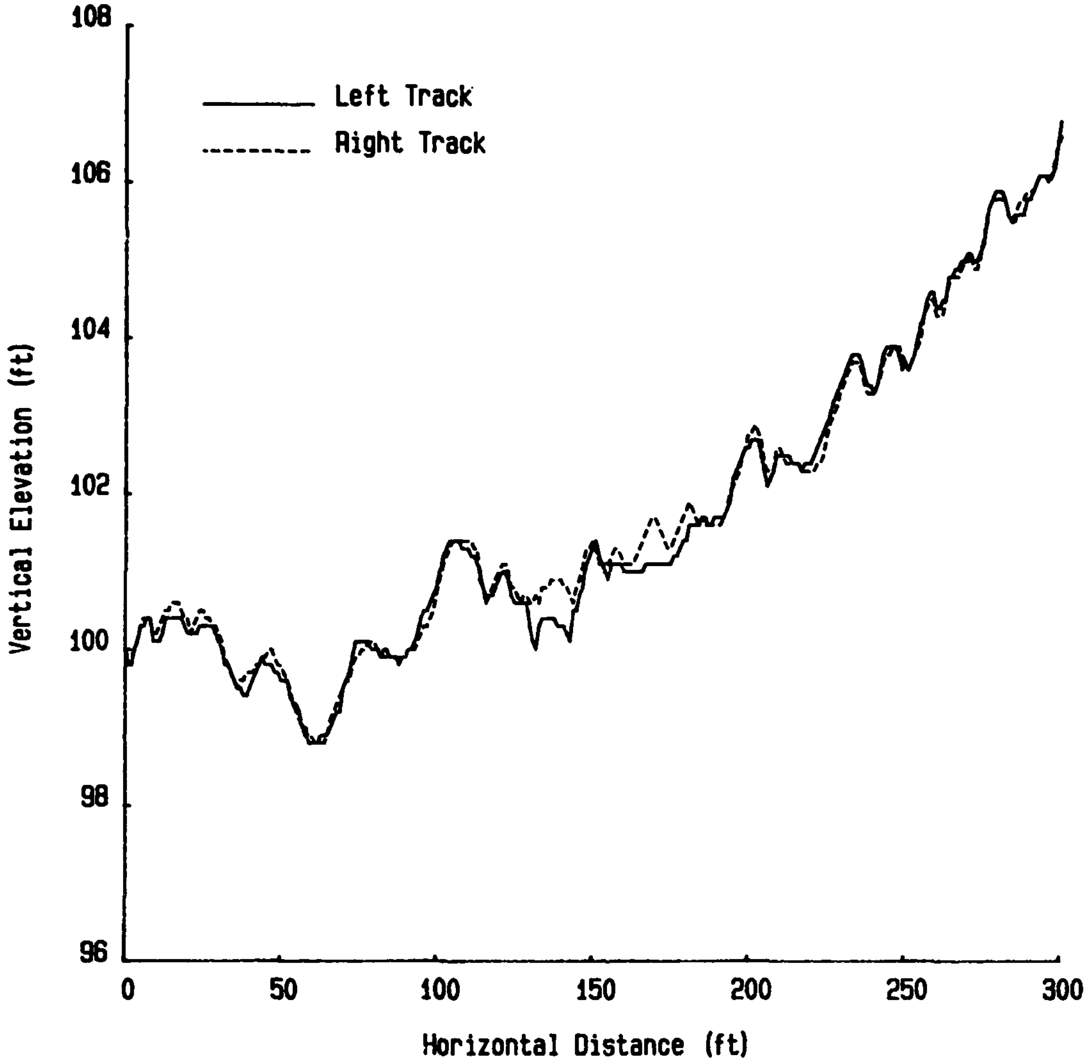
Test No.	Test Area	Speed mph	Time Required To Stop sec	Distance Required To Stop ft	Observer's Comments	Drivers' Comments
			Driver: May			
1	Vicksburg Airport*	6.3	1.3	9.5	No problem	
2	Vicksburg Airport*	10.9	1.6	17.4	No problem	
3	Vicksburg Airport*	16.2	2.6	41.5	No problem	
4	Vicksburg Airport*	21.0	2.6	62.0	Driver's response seemed slow	Slow response
5	Vicksburg Airport*	26.7	3.1	79.0	No problem	
6	Vicksburg Airport*	25.3	3.1	69.0	No problem	
7	Vicksburg Airport*	35.0	4.2	123.0	No problem	
			Driver: May			
1	WES**	6.6	1.3	7.8	No problem	
2	WES**	10.7	1.5	13.4	No problem	
3	WES**	13.1	2.2	23.8	No problem	
4	WES**	14.7	2.3	30.1	No problem	
5	WES**	18.8	2.4	39.4	No problem	
6	WES**	23.5	2.7	49.0	No problem	
7	WES**	27.2	2.7	54.0	No problem	
8	WES**	28.4	2.8	60.5	No problem	

(Continued)

* Damp asphalt surface.
** Dry asphalt surface.

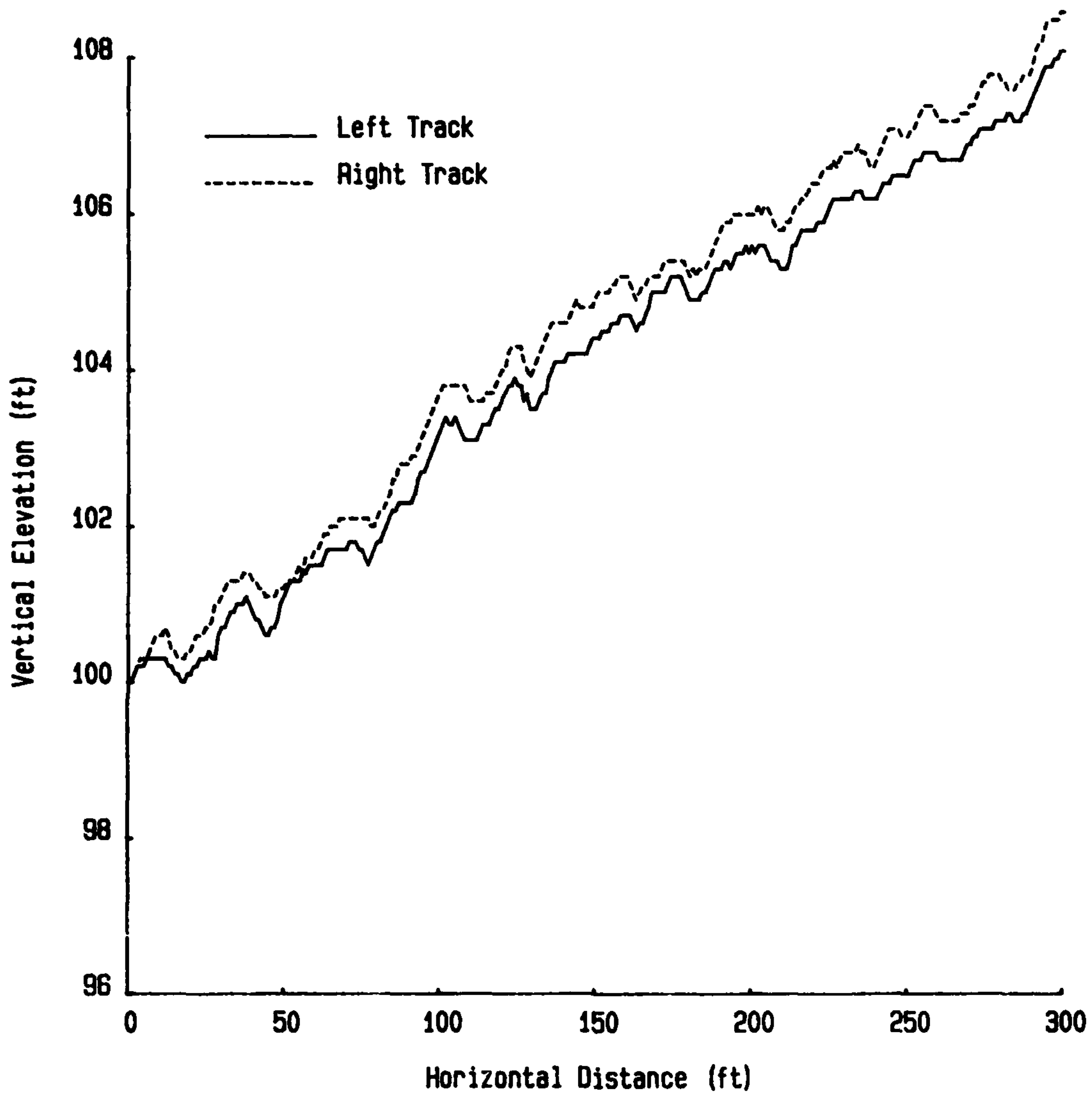
Table 9 (Concluded)

Test No.	Test Area	Speed mph	Time Required To Stop sec	Distance Required To Stop ft	Observer's Comments	Drivers' Comments
			Driver: Strong			
1	WES**	6.3	1.4	9.1	No problem	
2	WES**	11.0	1.5	15.0	No problem	
3	WES**	16.3	1.8	23.0	No problem	
4	WES**	19.0	2.4	41.0	Seemed slow	Slow response
5	WES**	24.2	2.8	52.0	Seemed slow	



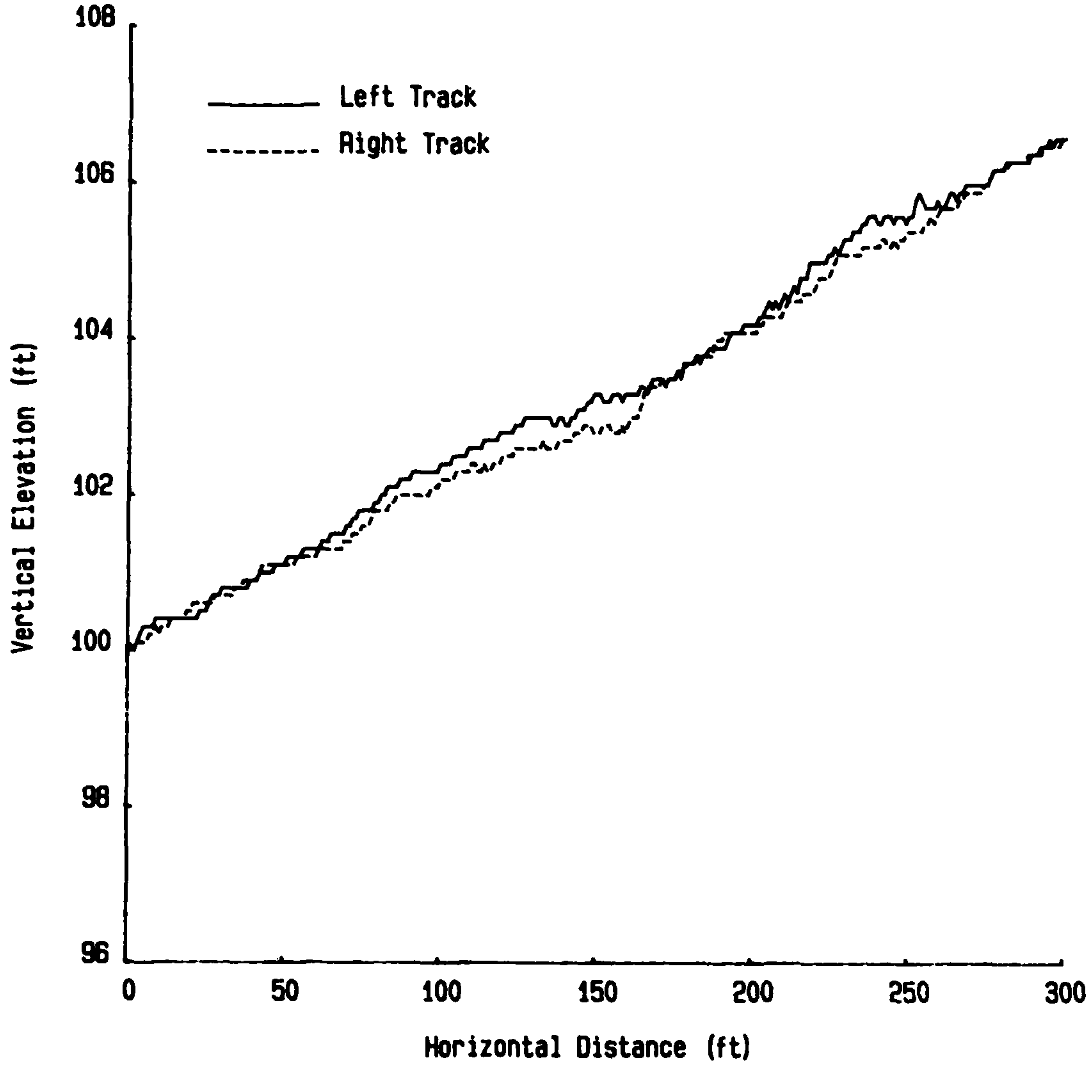
ELEVATION PROFILES
FOR RIDE COURSE 1

PLATE 1



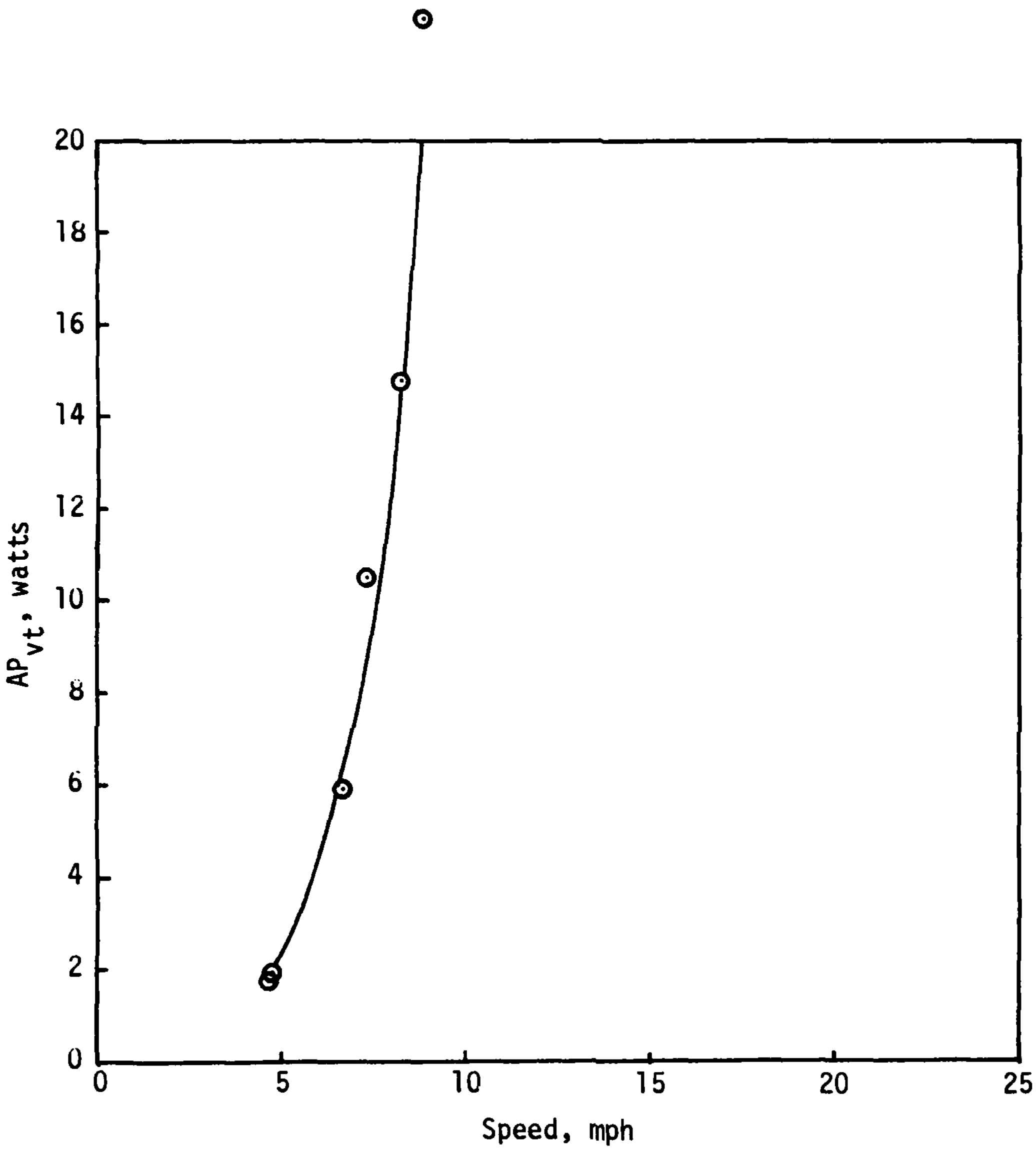
ELEVATION PROFILES
FOR RIDE COURSE 2

PLATE 2



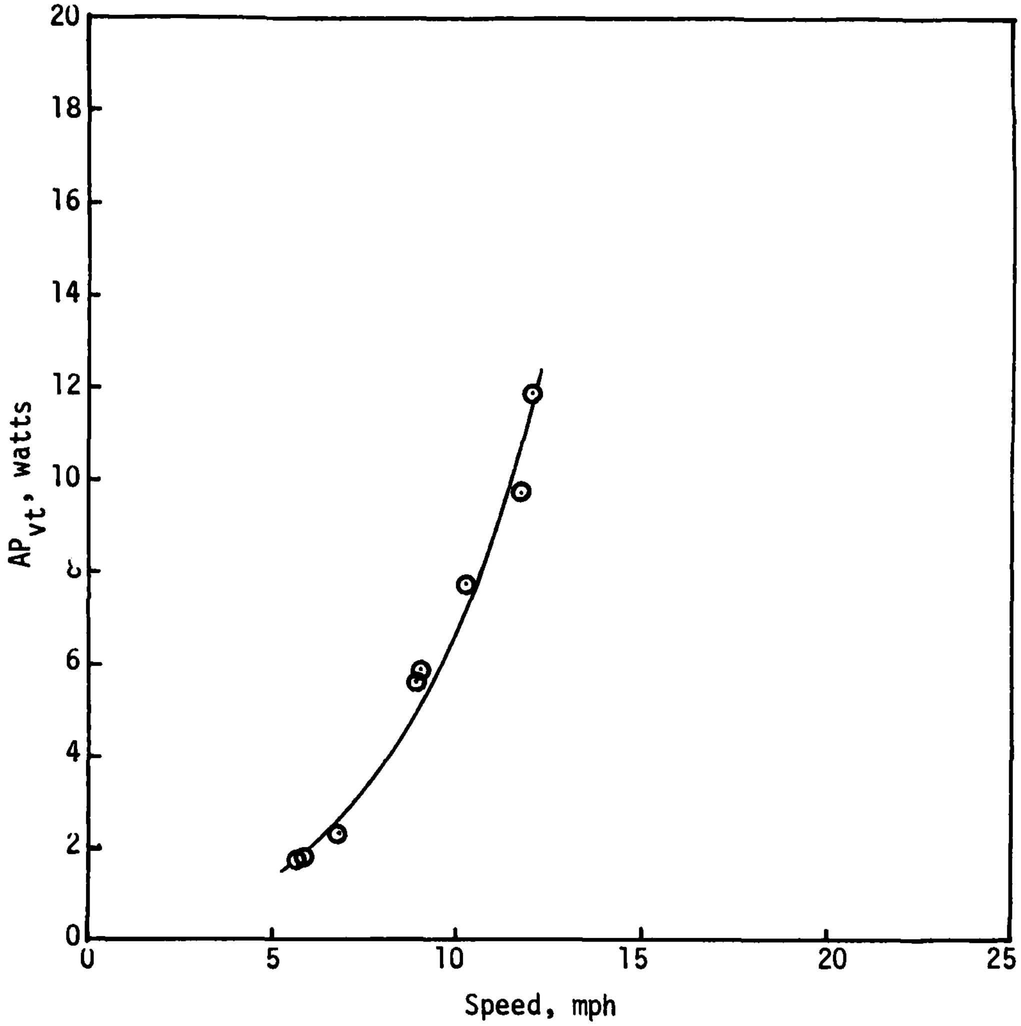
ELEVATION PROFILES
FOR RIDE COURSE 9

PLATE 3



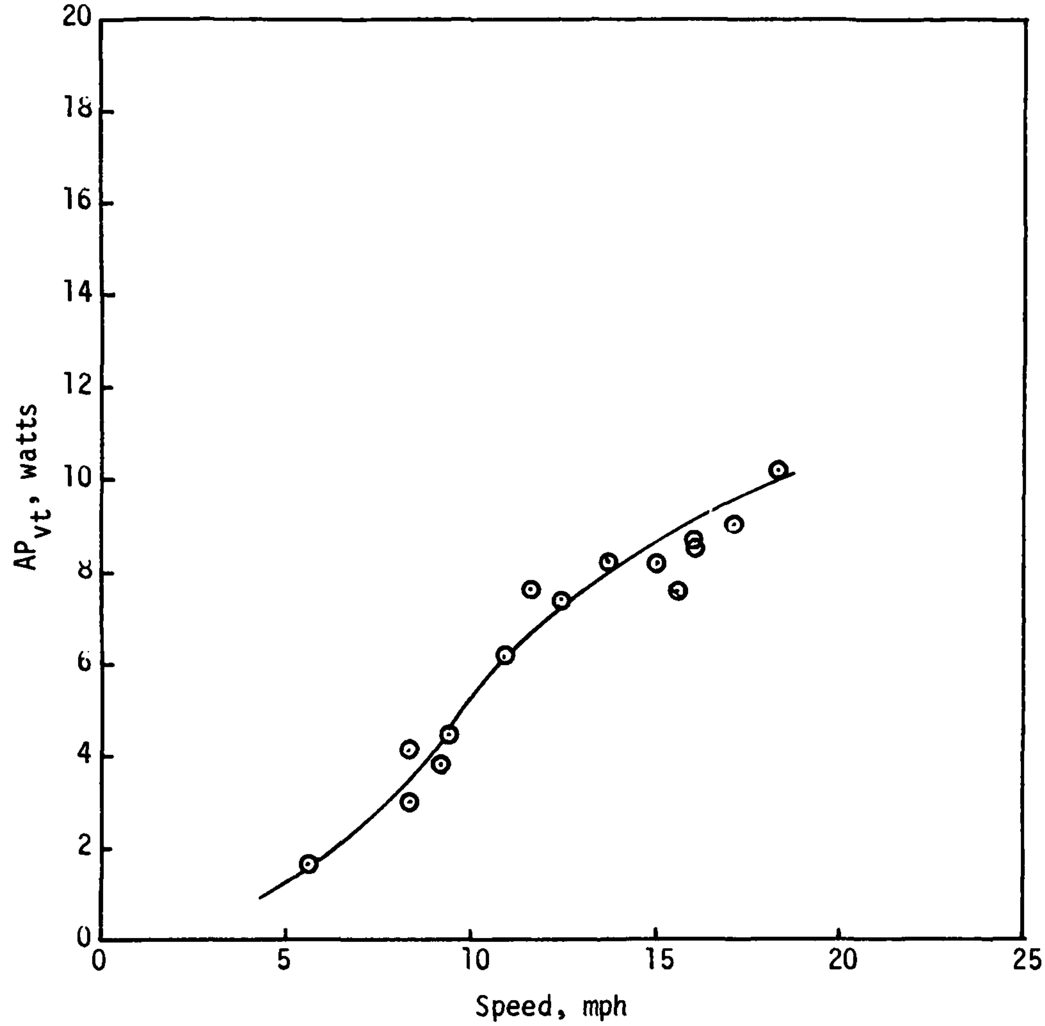
RIDE RESPONSE ON DRIVER'S SEAT
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 2.62
TEST COURSE 1

PLATE 4



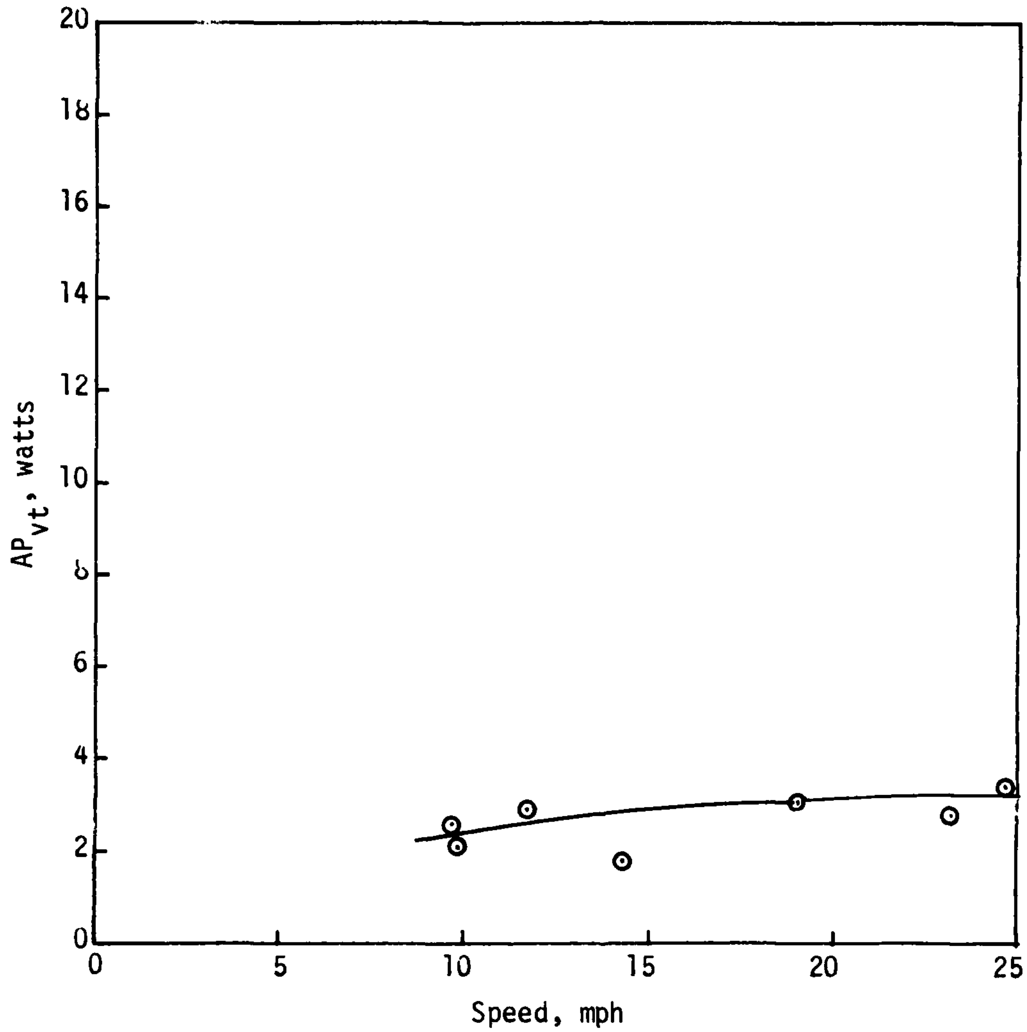
RIDE RESPONSE ON DRIVER'S SEAT
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 1.55
TEST COURSE 2

PLATE 5



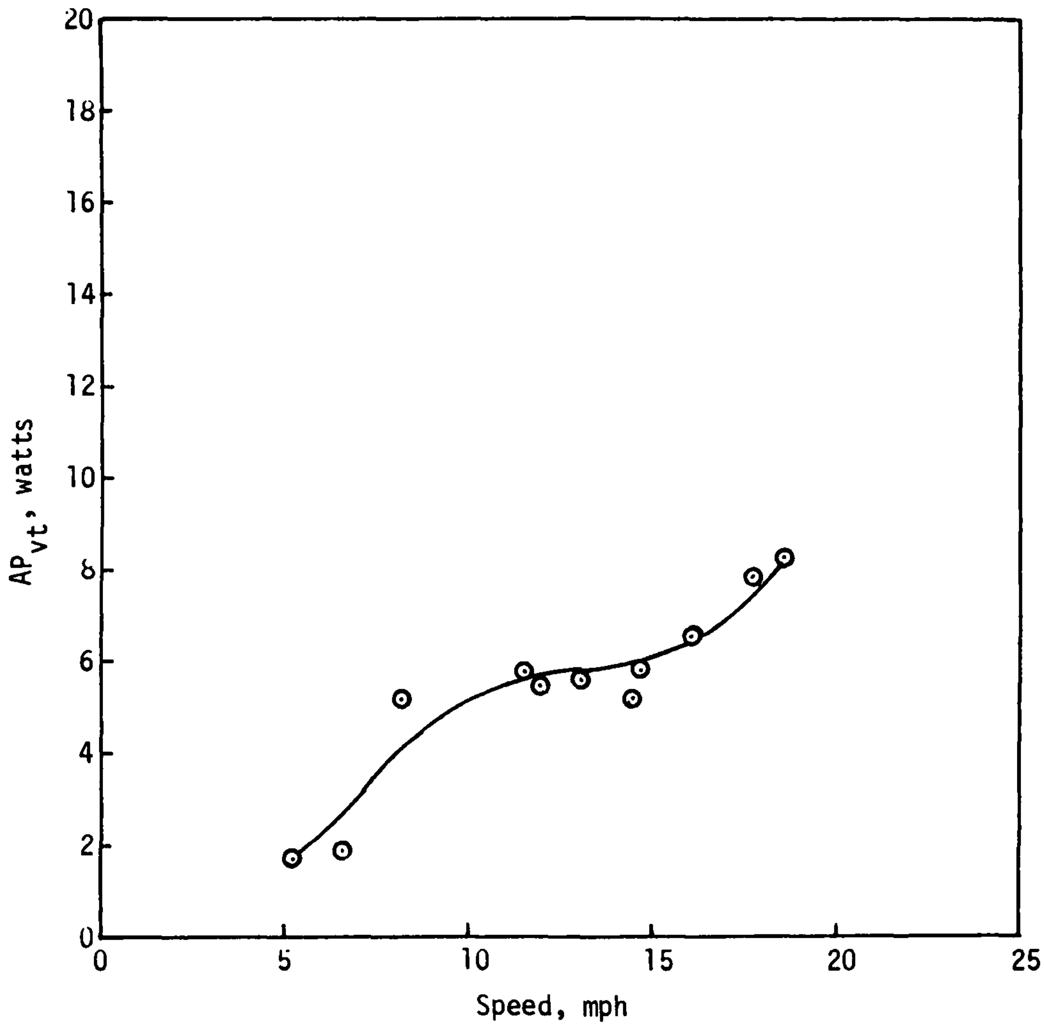
RIDE RESPONSE ON DRIVER'S SEAT
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 0.69
TEST COURSE 4

PLATE 6



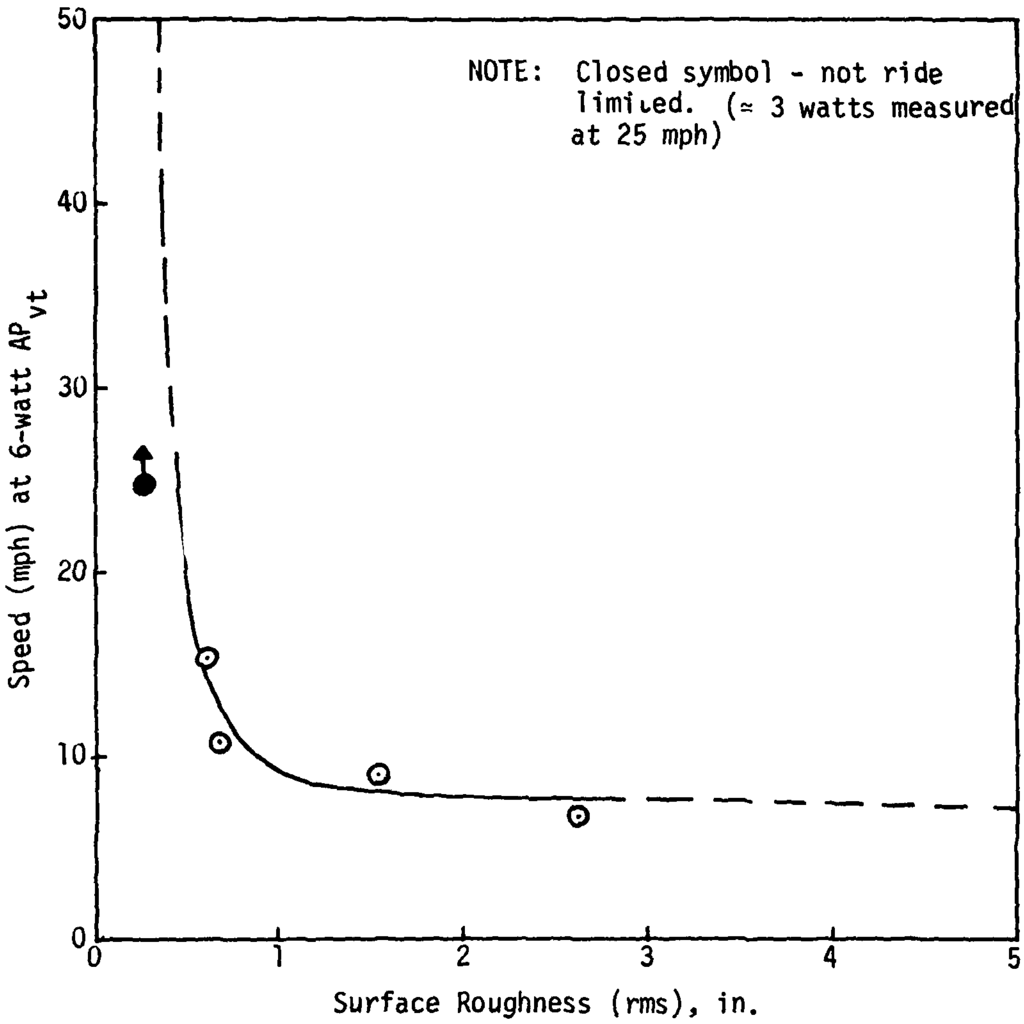
RIDE RESPONSE ON DRIVER'S SEAT
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 0.28
TEST COURSE 8

PLATE 7



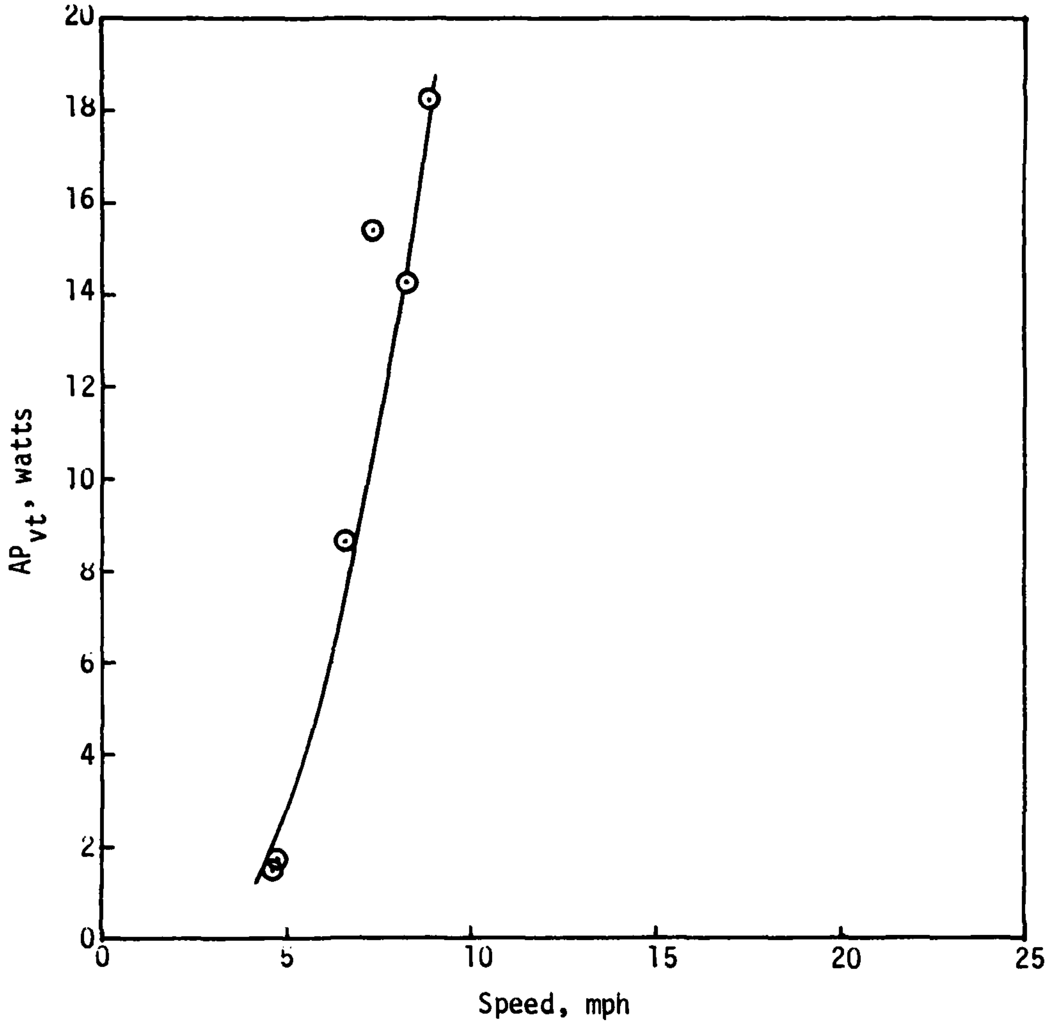
RIDE RESPONSE ON DRIVER'S SEAT
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 0.61
TEST COURSE 9

PLATE 8



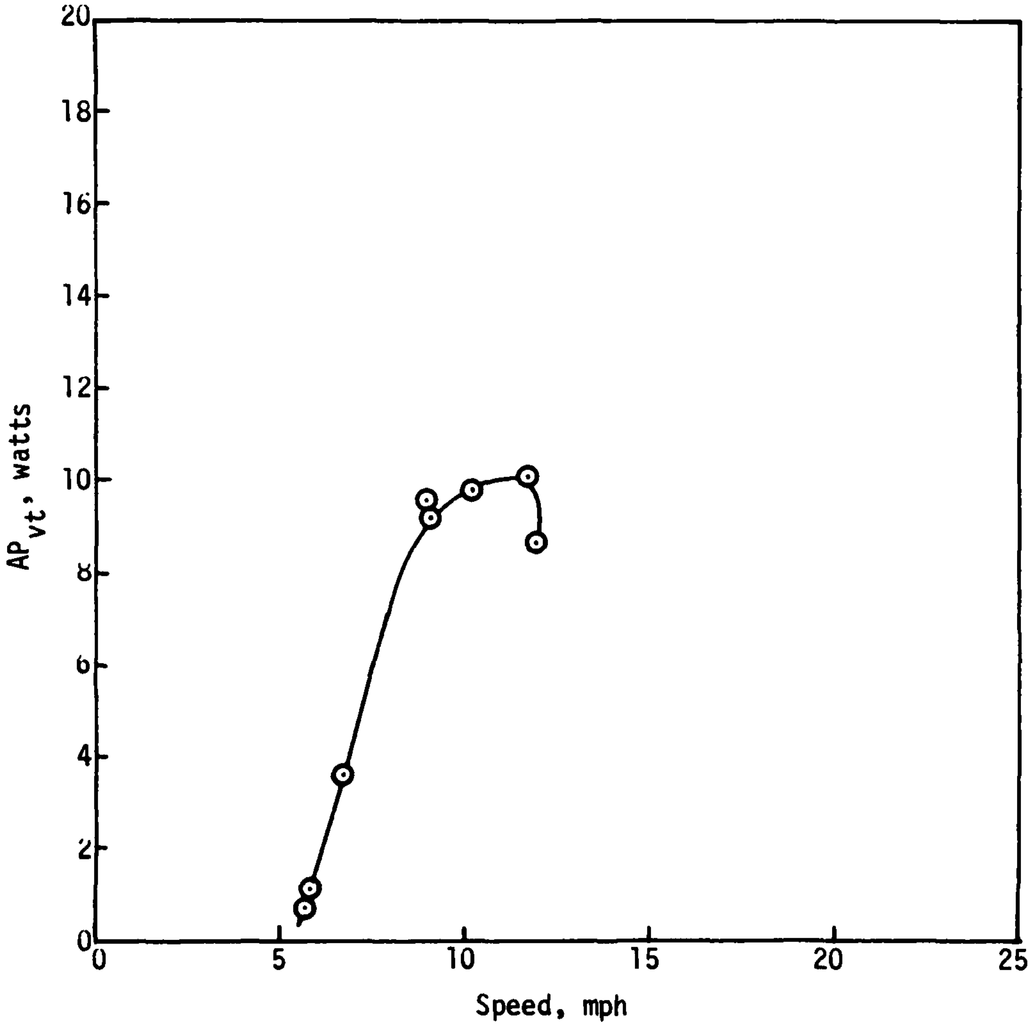
RIDE PERFORMANCE
M813A1 AND M812A1
ROLAND WHEELED VEHICLE SYSTEM

PLATE 9



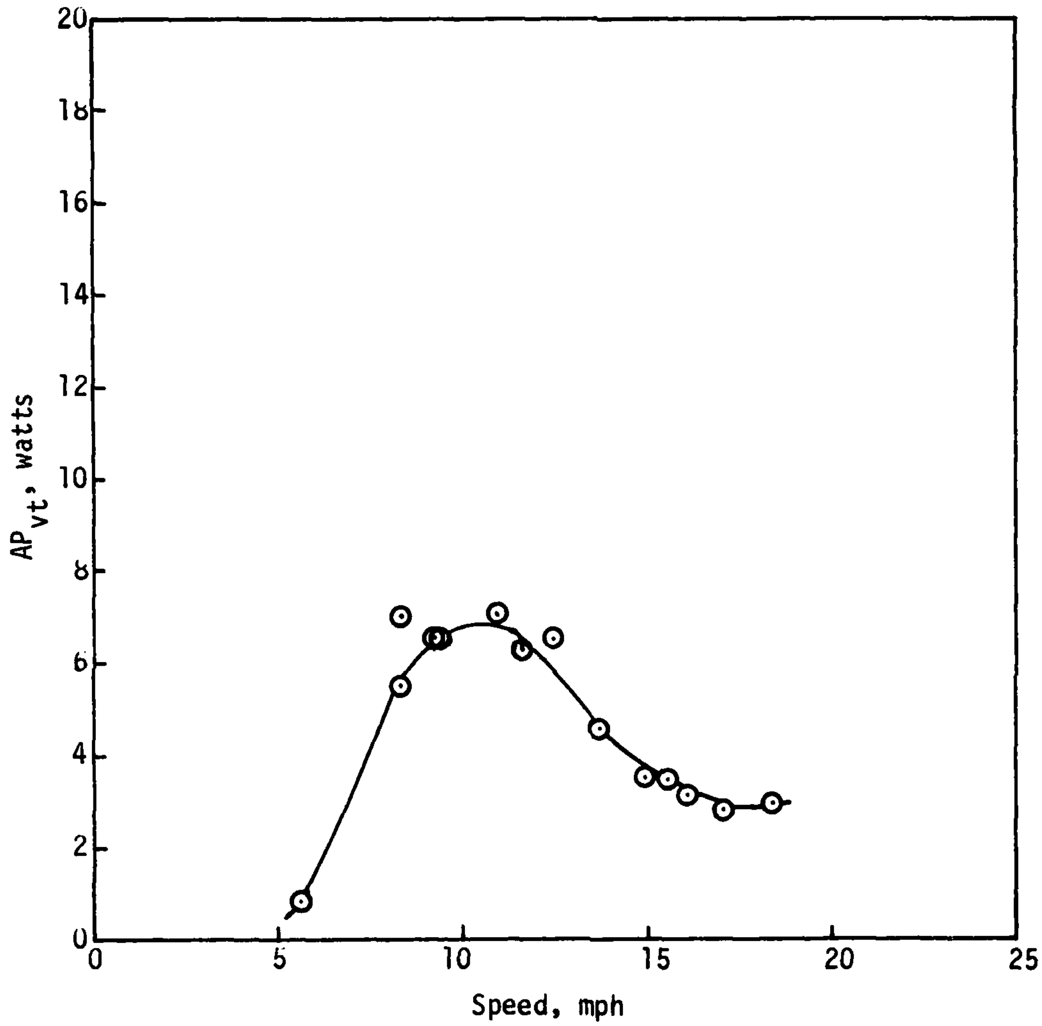
RIDE RESPONSE AT COMMANDER'S STATION
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 2.62
TEST COURSE 1

PLATE 10



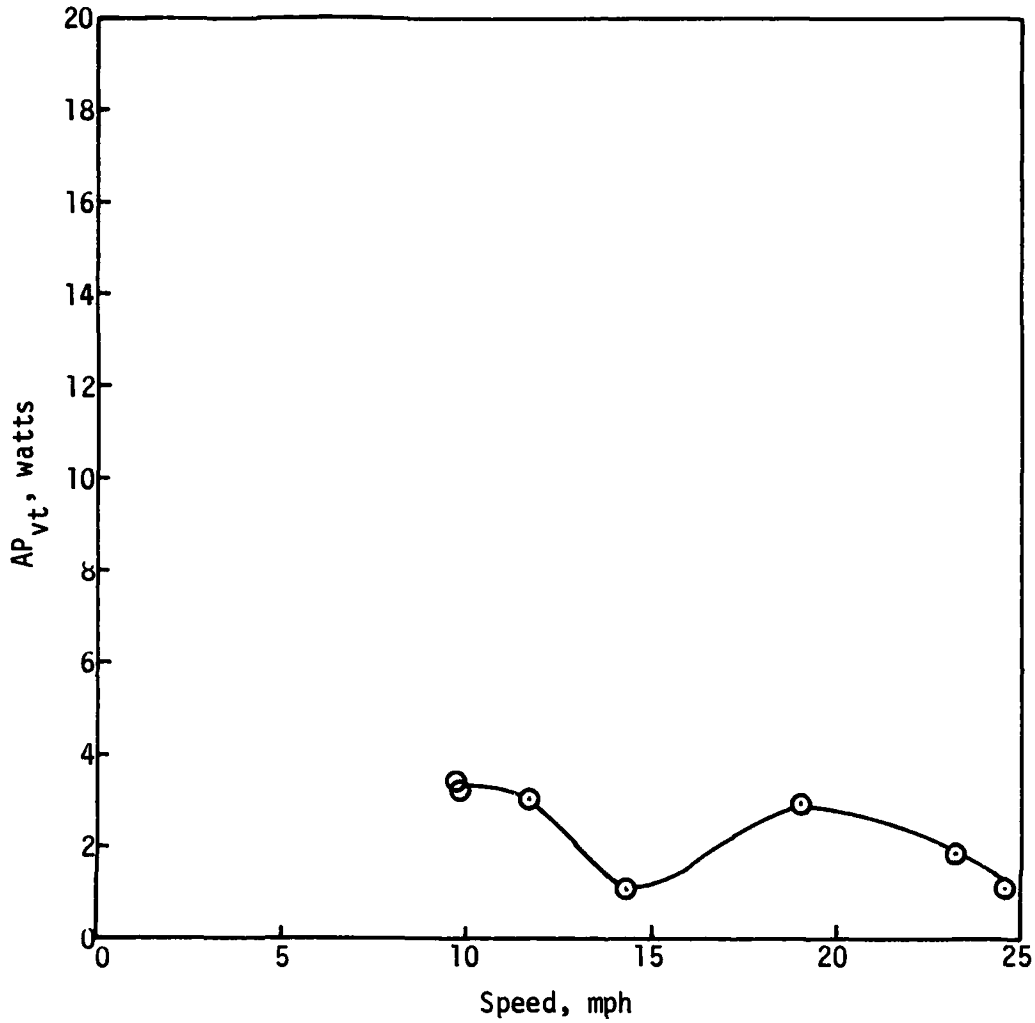
RIDE RESPONSE AT COMMANDER'S STATION
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 1.55
TEST COURSE 2

PLATE 11



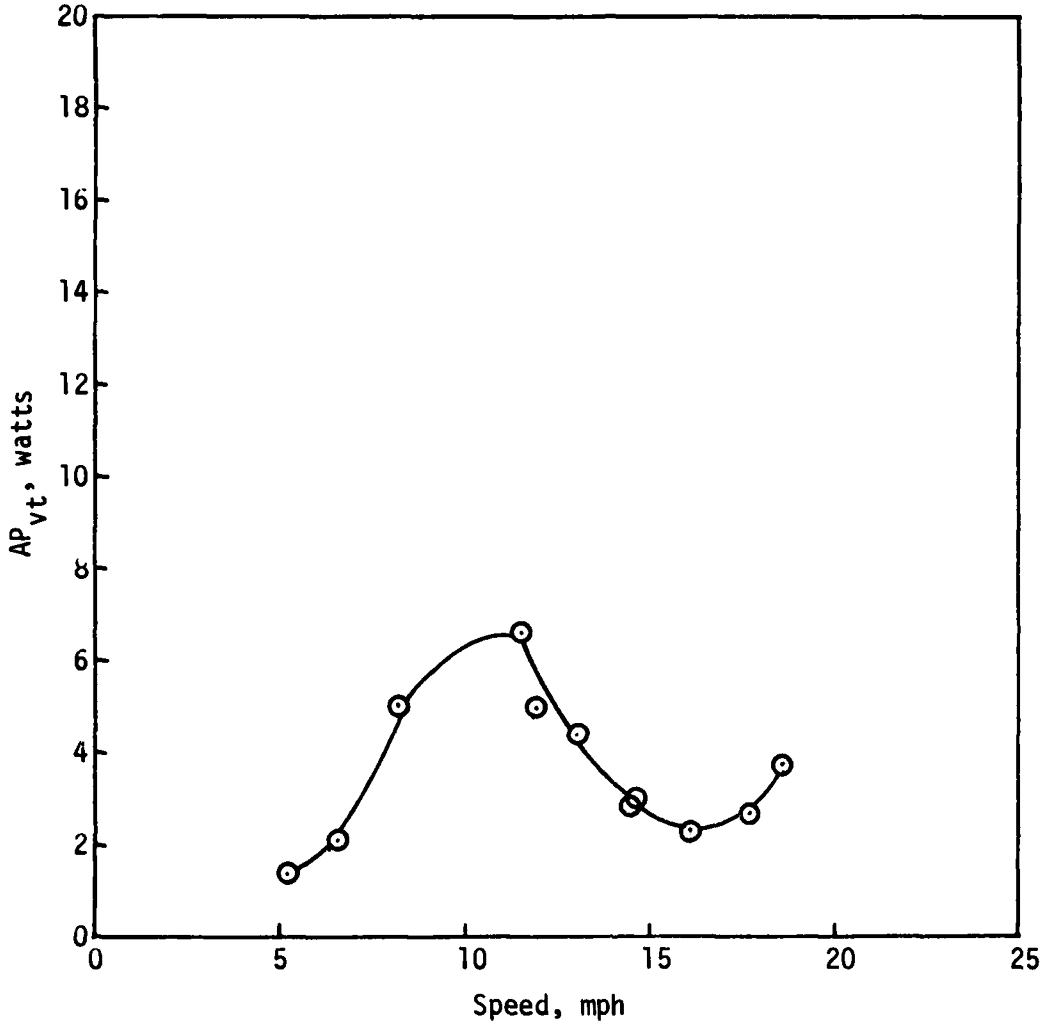
RIDE RESPONSE AT COMMANDER'S STATION
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 0.69
TEST COURSE 4

PLATE 12



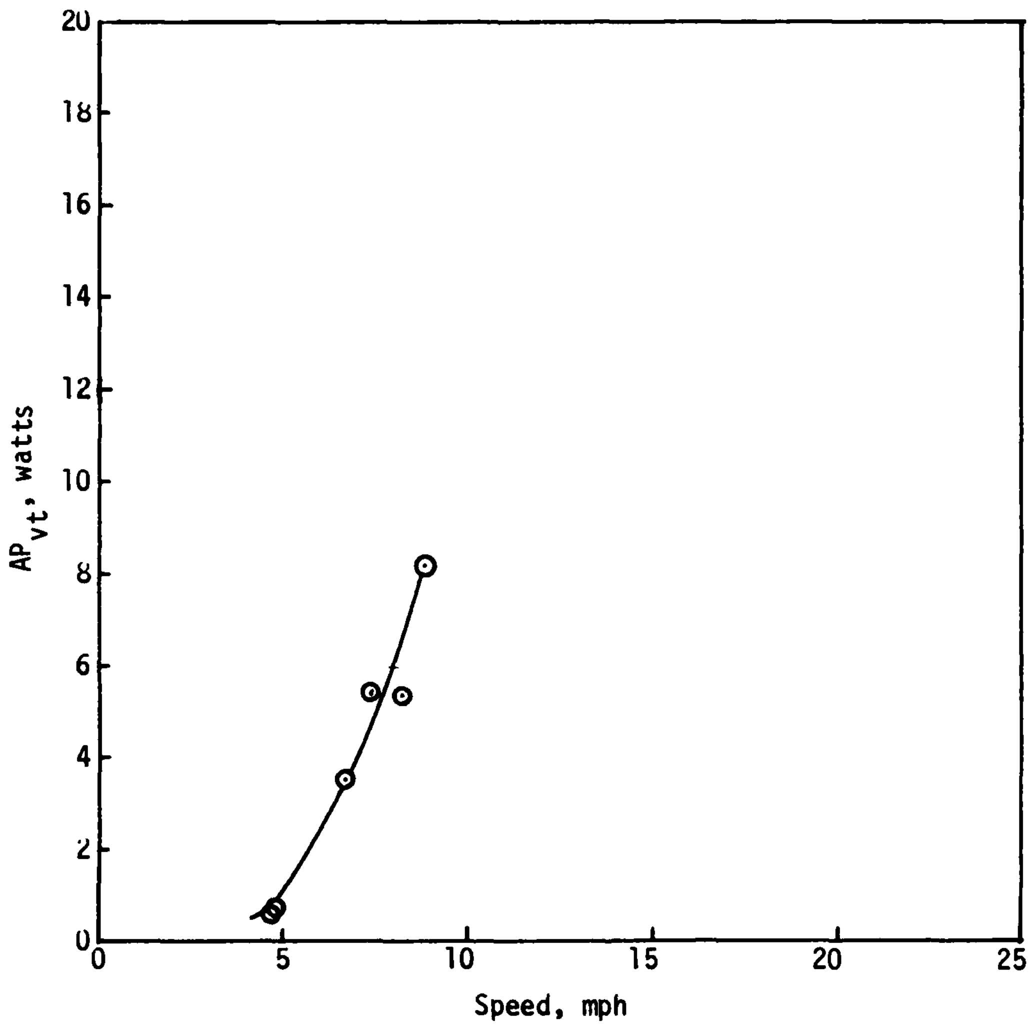
RIDE RESPONSE AT COMMANDER'S STATION
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 0.28
TEST COURSE 8

PLATE 13



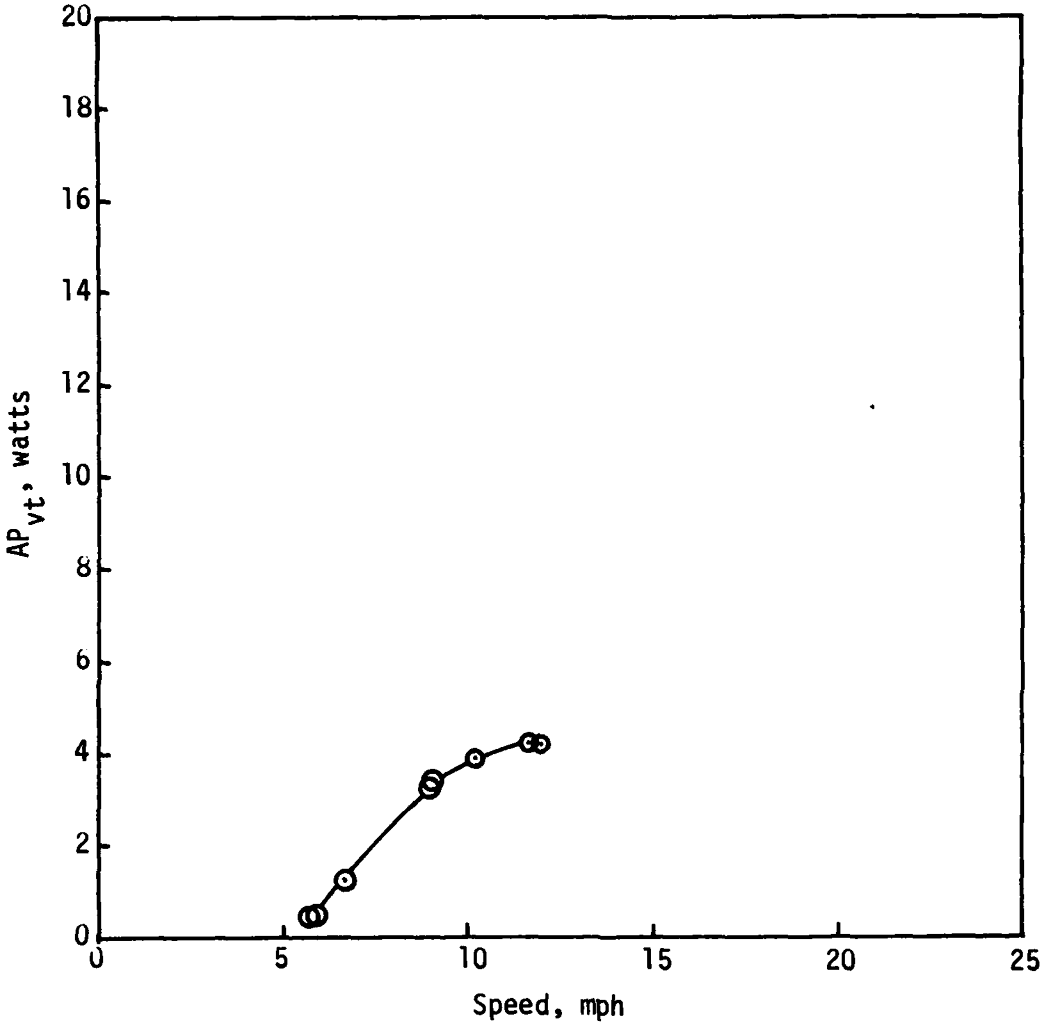
RIDE RESPONSE AT COMMANDER'S STATION
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 0.61
TEST COURSE 9

PLATE 14



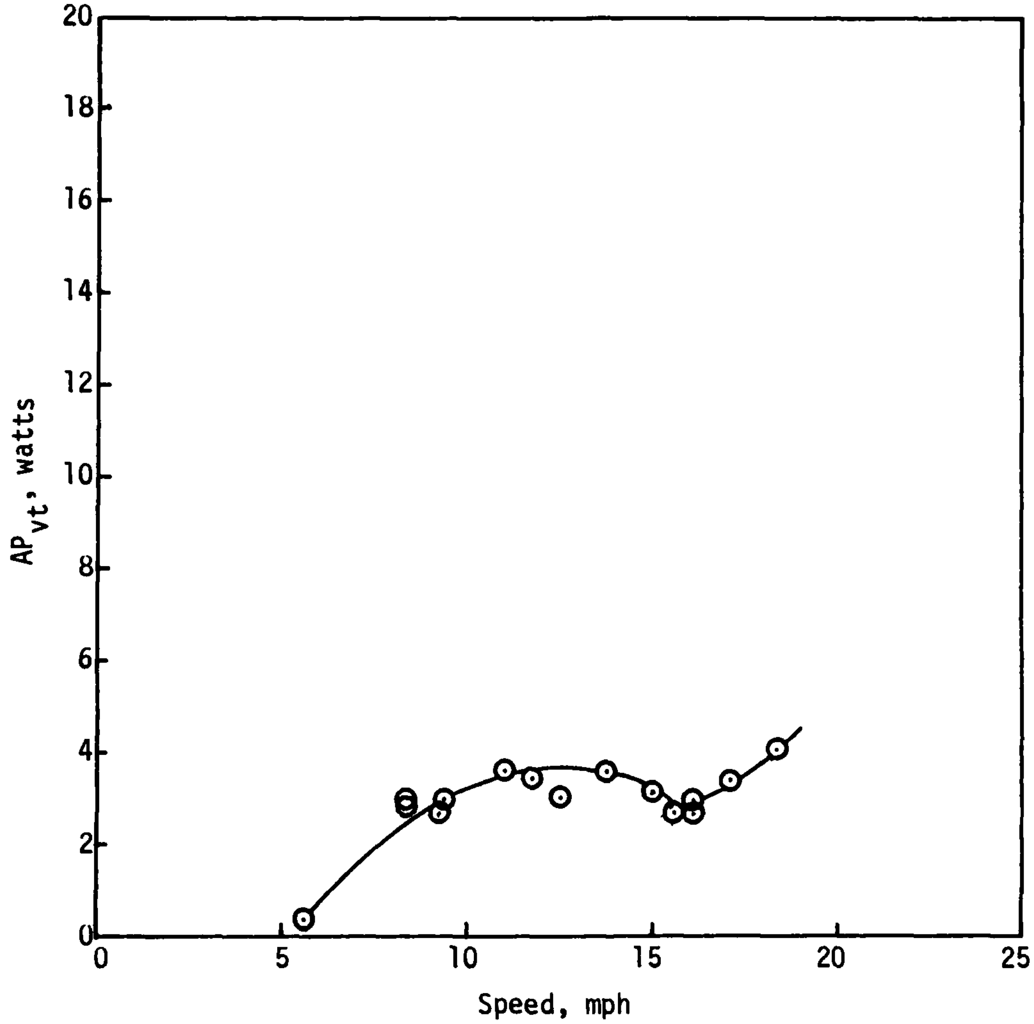
RIDE RESPONSE AT THE CENTER OF GRAVITY
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 2.62
TEST COURSE 1

PLATE 15



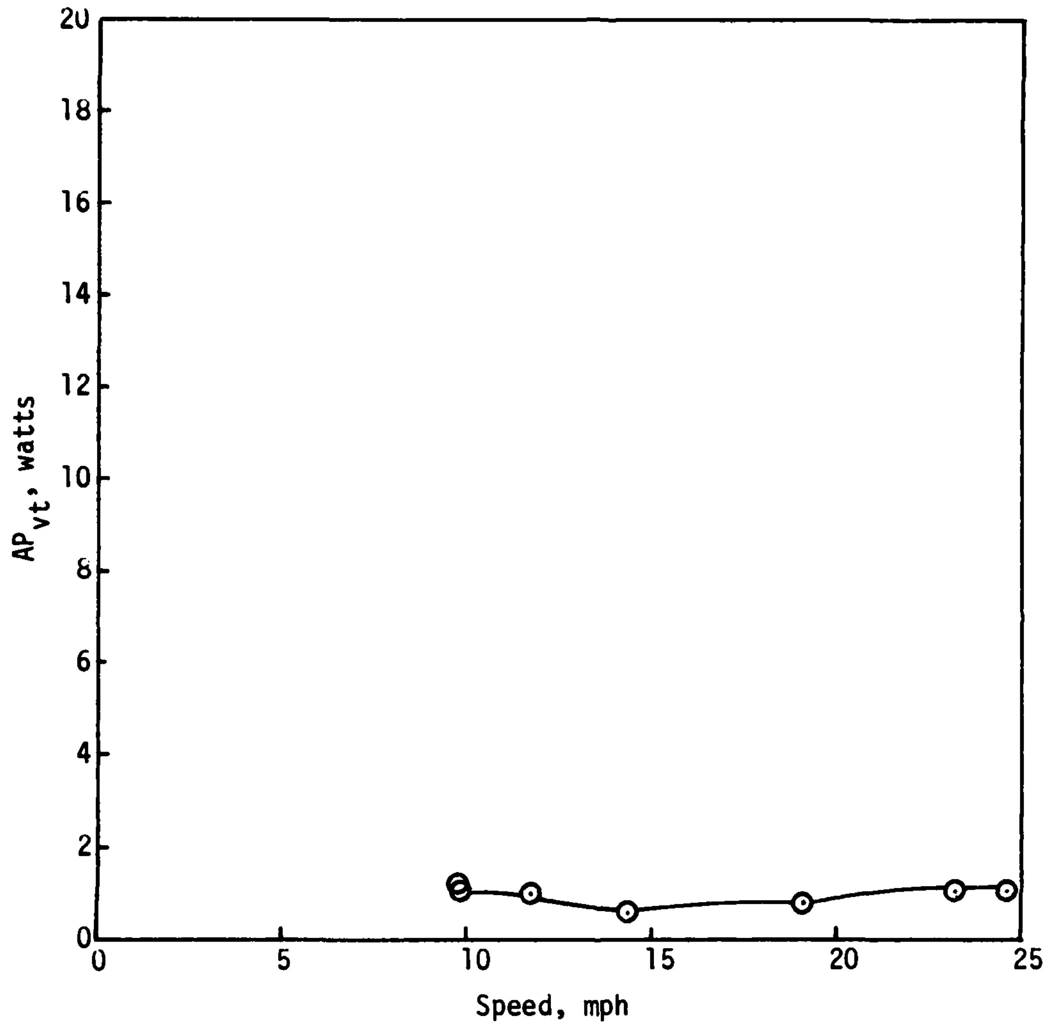
RIDE RESPONSE AT THE CENTER OF GRAVITY
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 1.55
TEST COURSE 2

PLATE 16



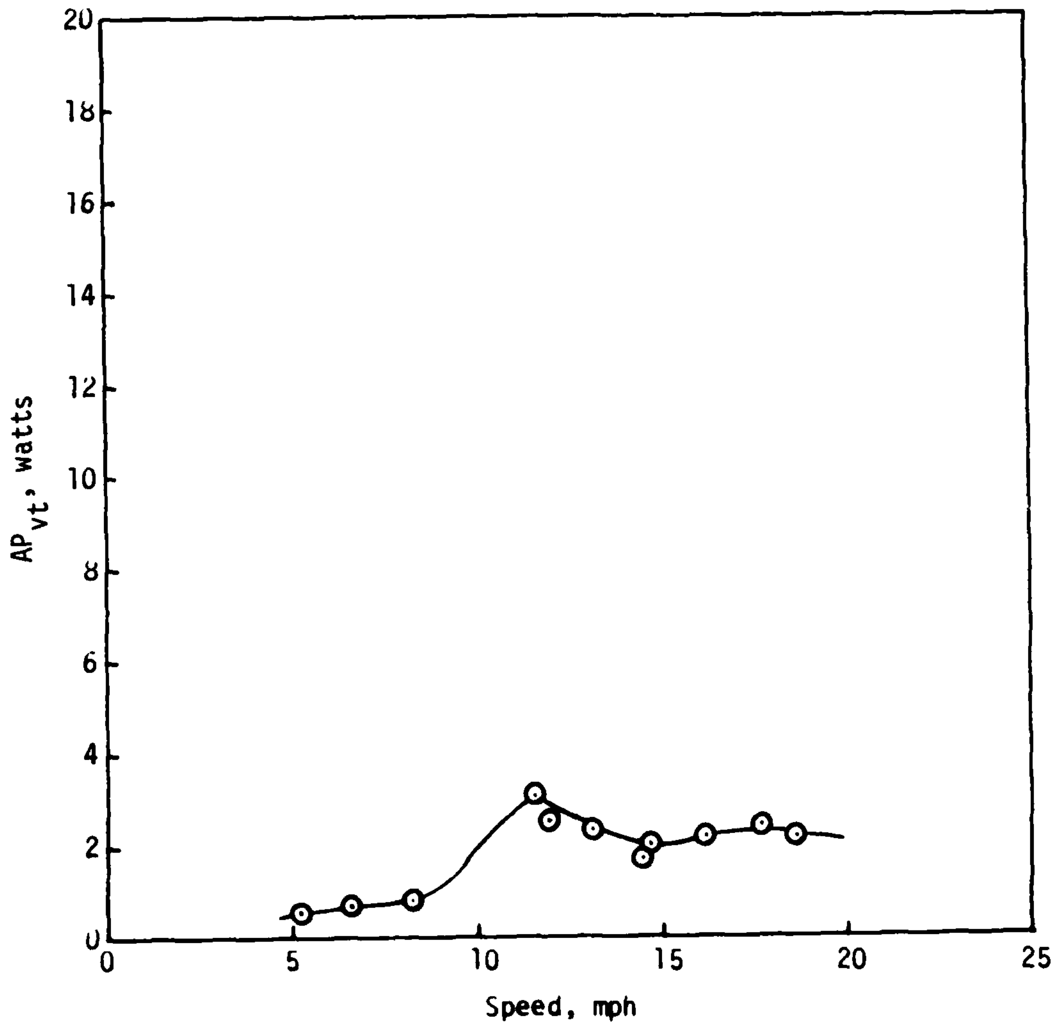
RIDE RESPONSE AT THE CENTER OF GRAVITY
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 0.69
TEST COURSE 4

PLATE 17



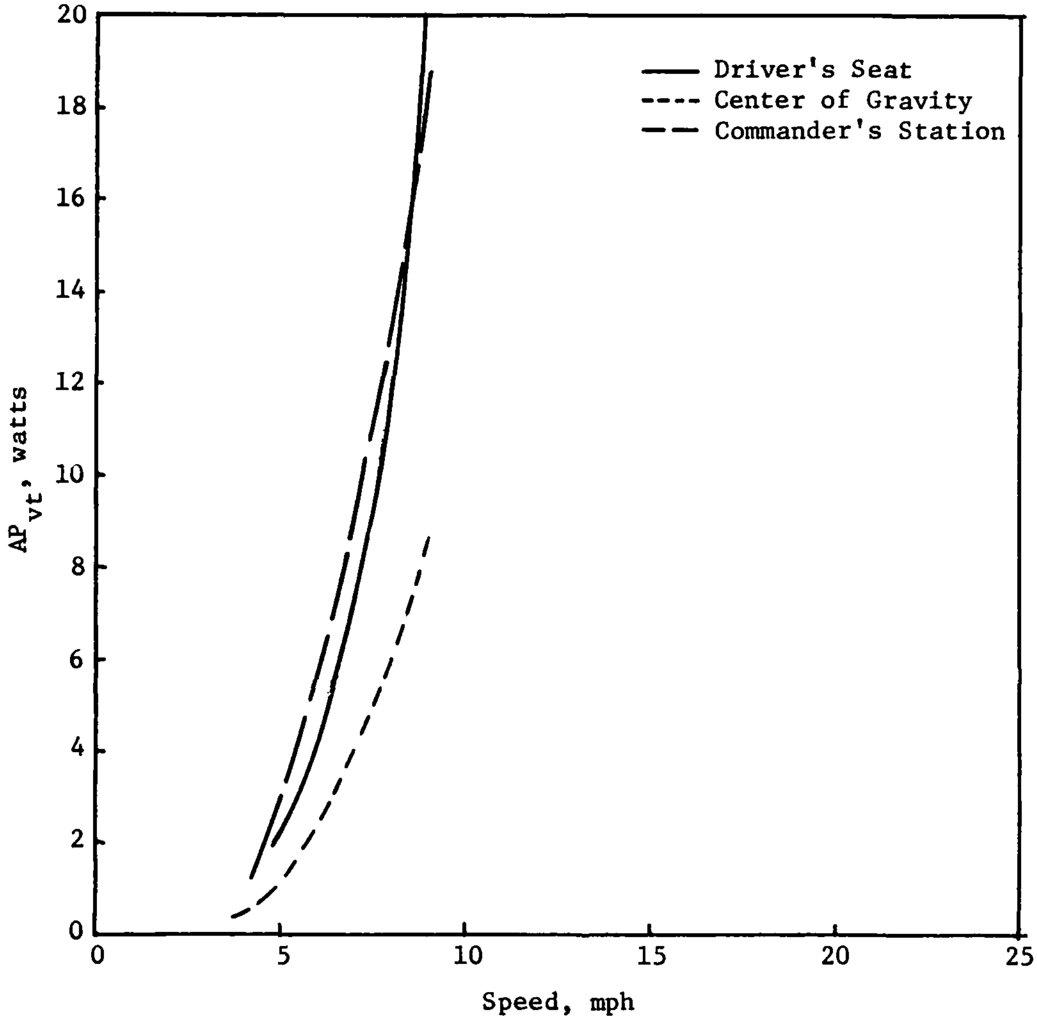
RIDE RESPONSE AT THE CENTER OF GRAVITY
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 0.28
TEST COURSE 8

PLATE 18



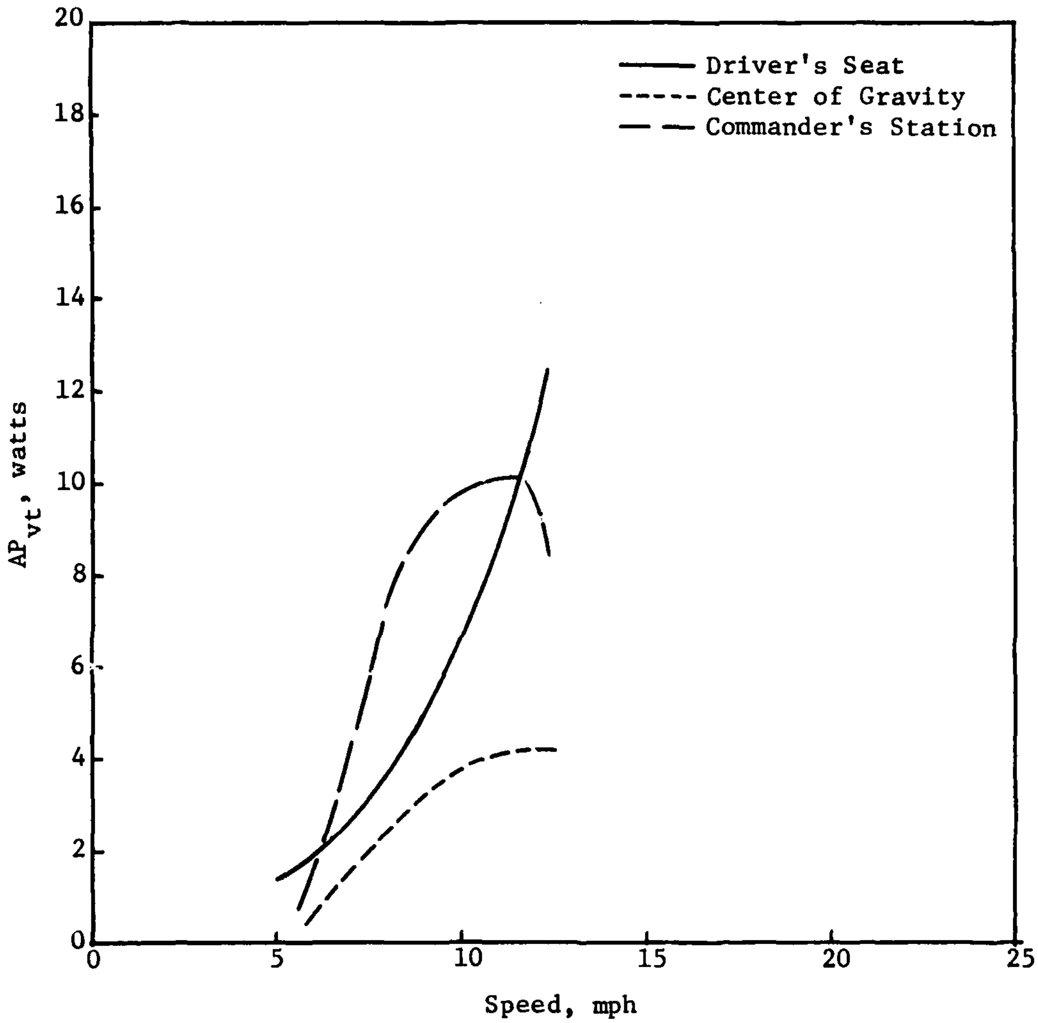
RIDE RESPONSE AT THE CENTER OF GRAVITY
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 0.61
TEST COURSE 9

PLATE 19



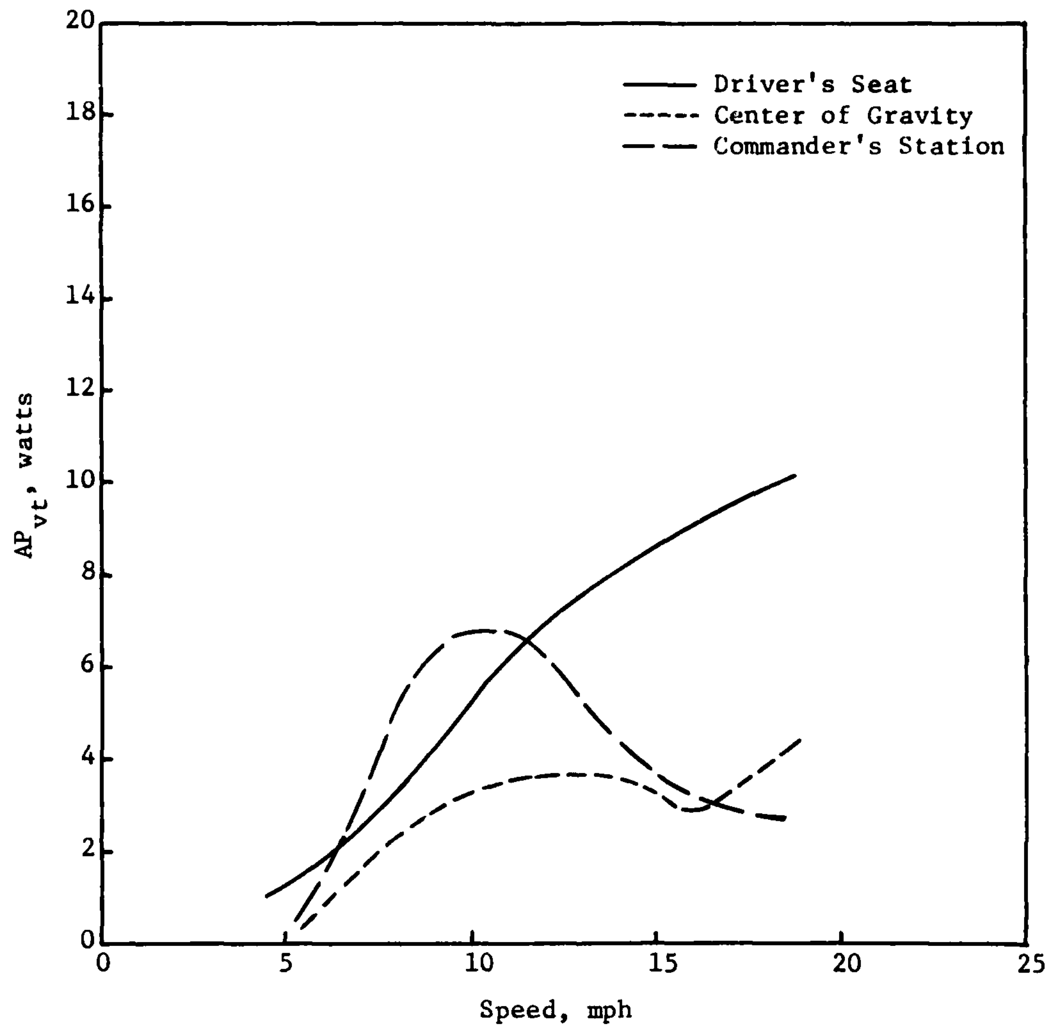
RIDE RESPONSE
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 2.62
TEST COURSE 1

PLATE 20



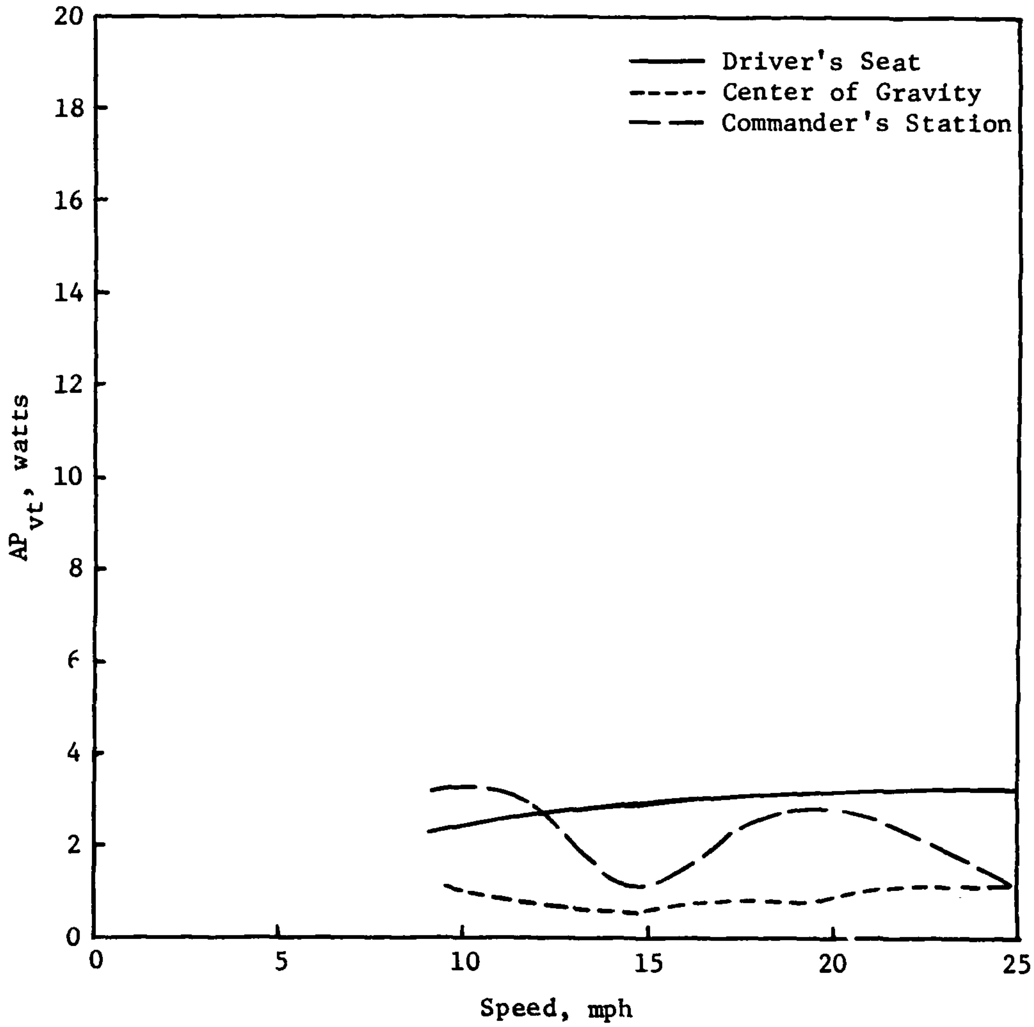
RIDE RESPONSE
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 1.55
TEST COURSE 2

PLATE 21



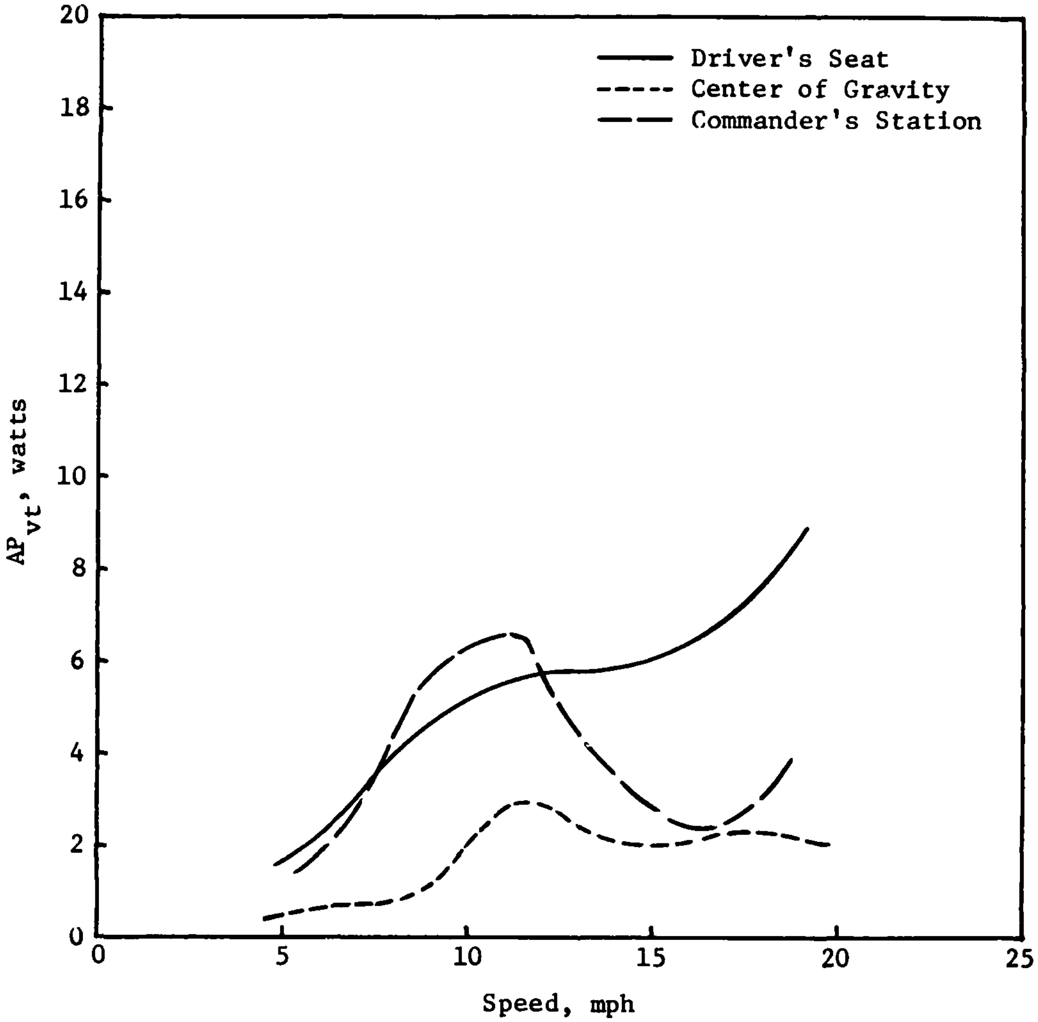
RIDE RESPONSE
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 0.69
TEST COURSE 4

PLATE 22



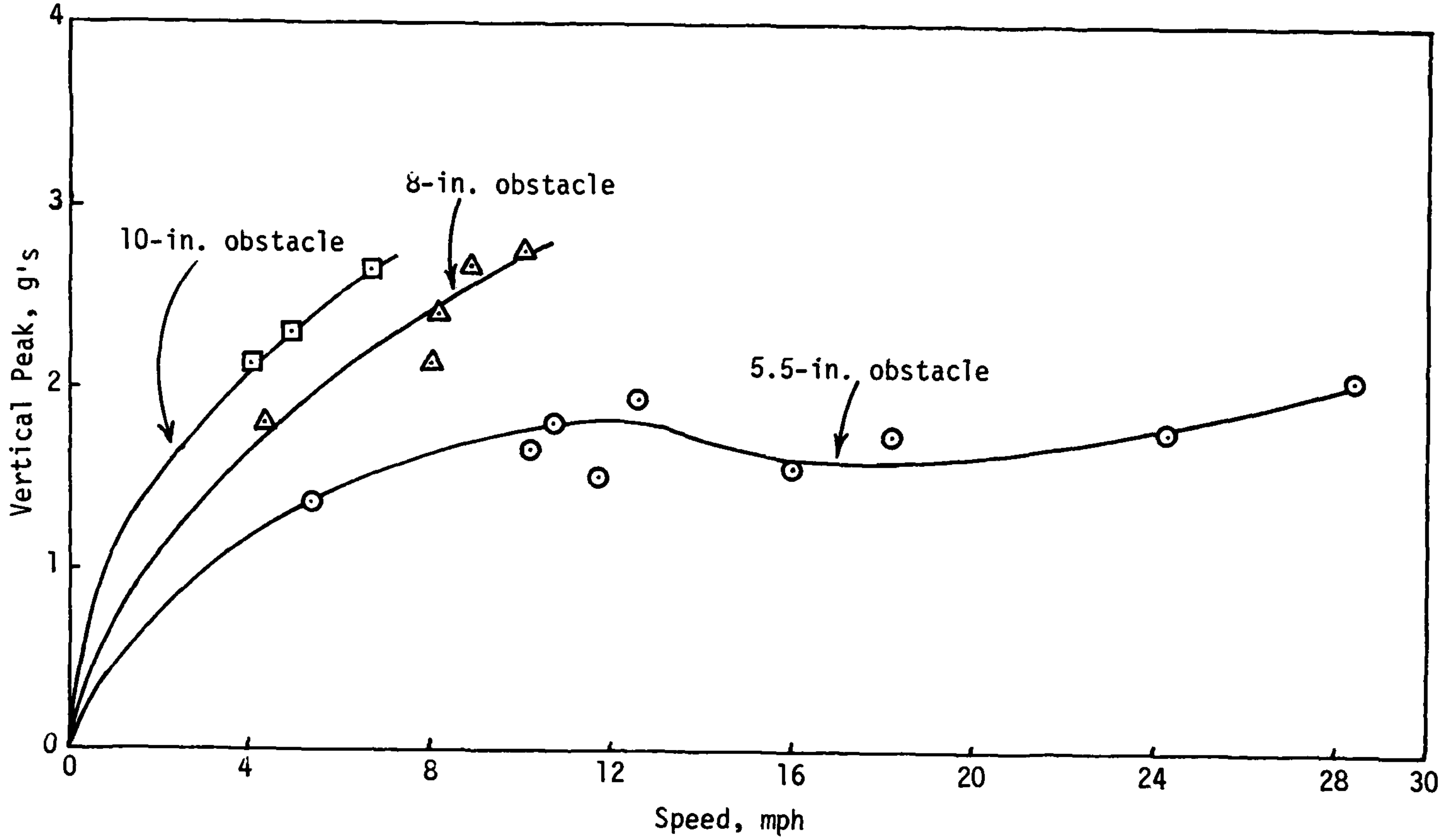
RIDE RESPONSE
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 0.28
TEST COURSE 8

PLATE 23



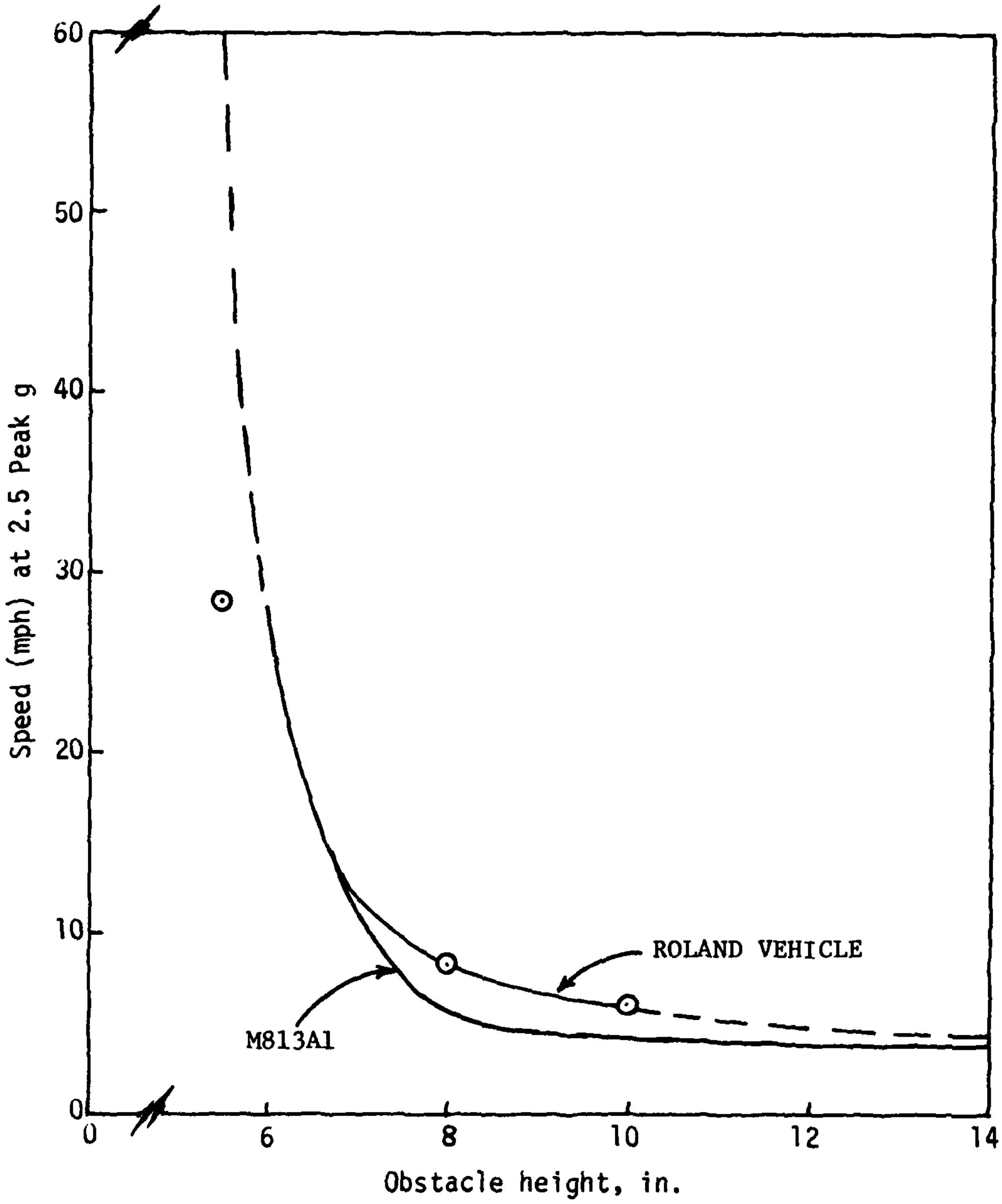
RIDE RESPONSE
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM
SURFACE ROUGHNESS (rms), in., 0.61
TEST COURSE 9

PLATE 24



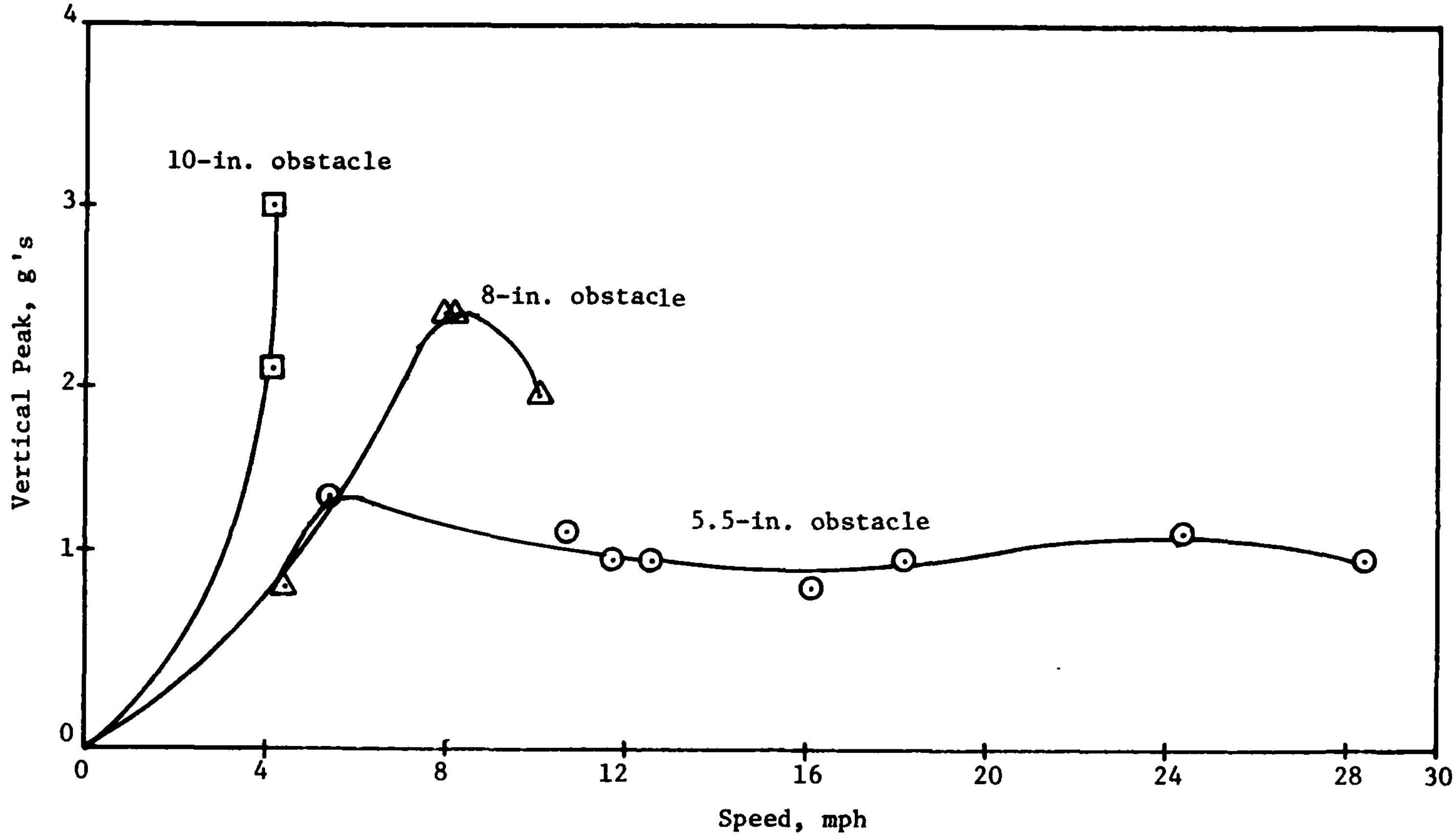
OBSTACLE-IMPACT RESPONSE
AT THE DRIVER'S SEAT
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM

PLATE 25



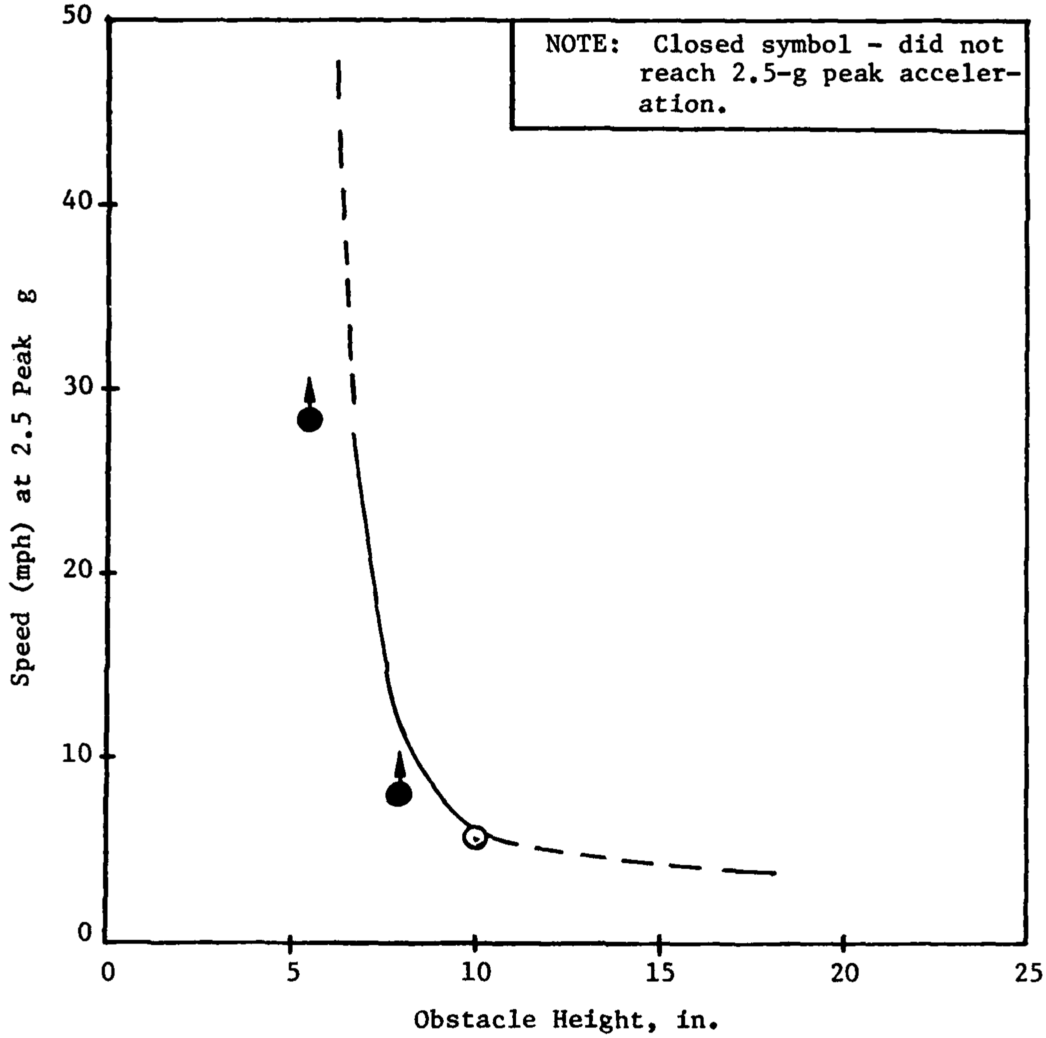
SHOCK PERFORMANCE
AT THE DRIVER'S SEAT
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM

PLATE 26



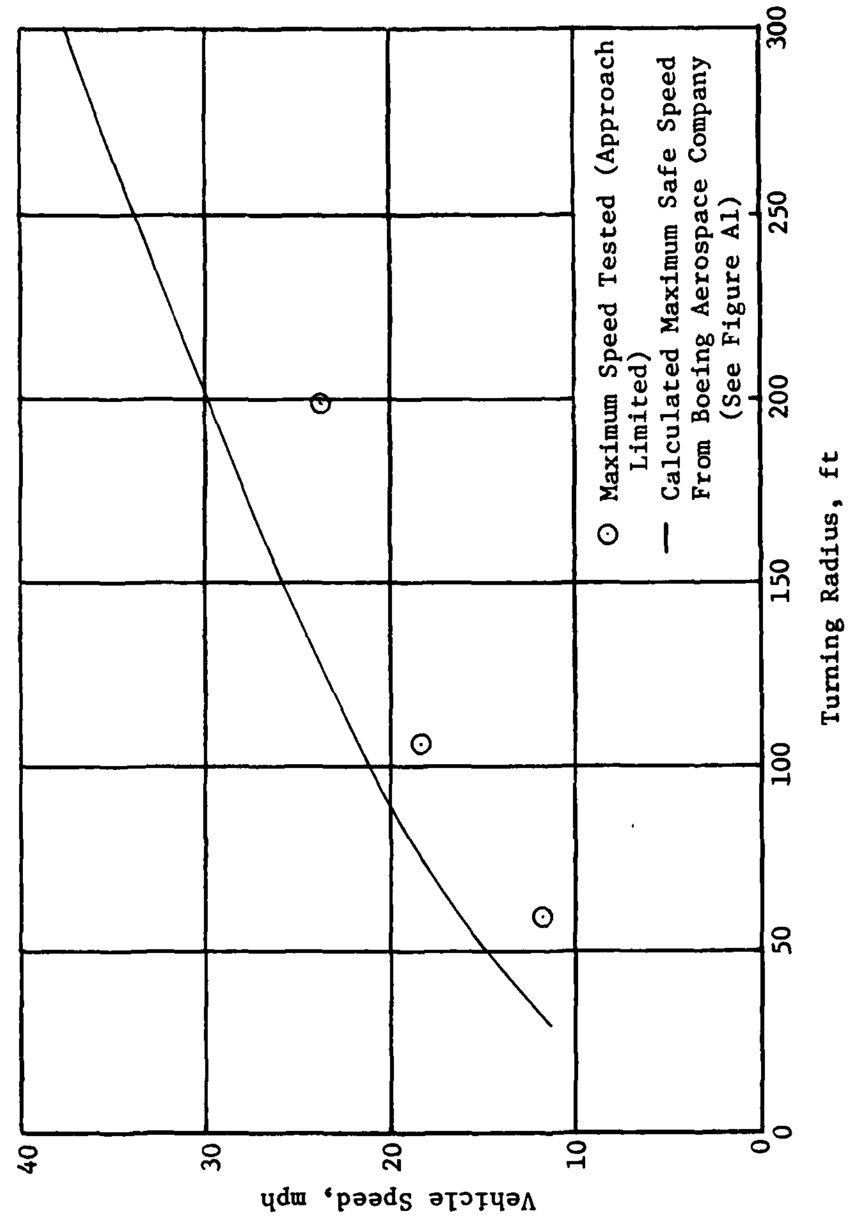
OBSTACLE-IMPACT RESPONSE
AT THE COMMANDER'S STATION
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM

PLATE 27



SHOCK PERFORMANCE
AT THE COMMANDER'S STATION
M812A1, 6x6
ROLAND WHEELED VEHICLE SYSTEM

PLATE 28



VEHICLE SPEED VERSUS TURNING RADIUS
ROLAND WHEELED VEHICLE SYSTEM
ASPHALT SURFACE

PLATE 29

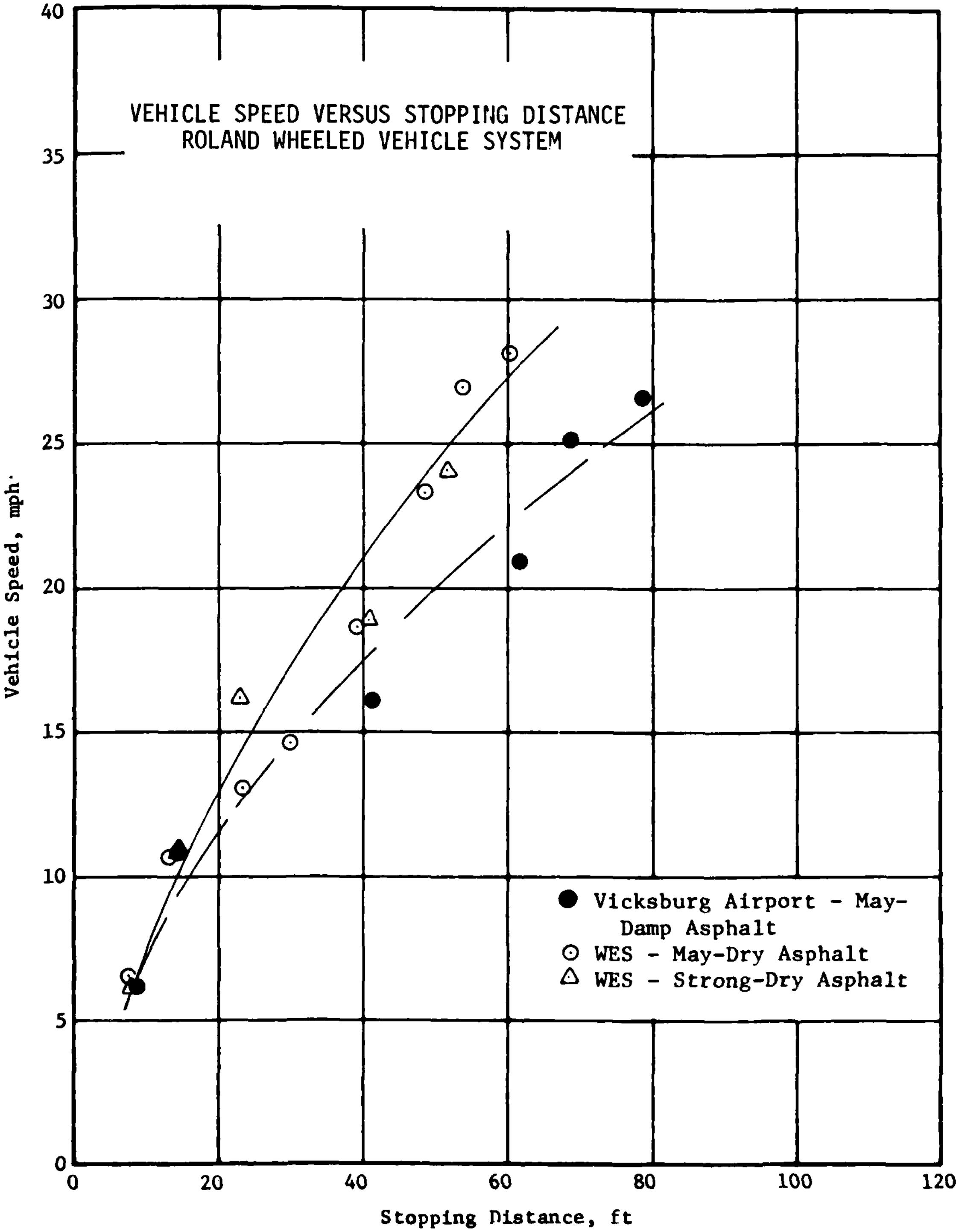

VEHICLE SPEED VERSUS STOPPING DISTANCE
ROLAND WHEELED VEHICLE SYSTEM
Vehicle Speed, mph
Stopping Distance, ft
Vicksburg Airport - May-Damp Asphalt
WES - May-Dry Asphalt
WES - Strong-Dry Asphalt
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
120

PLATE 30

APPENDIX A: MOBILITY TEST REQUIREMENTS, ROLAND WHEELED VEHICLE SYSTEM

1.0 Background

The ROLAND all-weather SHORADS system was originally configured for production to use the XM-975 (M-109 derivative) as the carrier for the Launcher System (Fire Unit). The ROLAND Program was recently restructured to have the Fire Unit transported by a wheeled vehicle for use by the Rapid Deployment Force. A trade-off study was conducted to determine the wheeled vehicle carrier that would meet requirements which included cost and schedule limitations. The carrier selected was an M812-A1 Military vehicle which had been used as the carrier for the HONEST JOHN Missile System. The HONEST JOHN Launcher was removed from the carrier and the trucks will be refurbished for ROLAND use. In addition to truck transport, the wheeled vehicle system must also have these additional capabilities:

a. Allow unloading of the Fire Unit from the truck to ground and loading from ground to truck.

b. Allow leveling for direct transfer to and from the C-141B aircraft.

c. Allow "Search on the Move."

d. Allow firing without restriction for azimuth and elevation.

e. Allow transport using the CH47D helicopter.

2.0 Test Objectives

a) To assess handling characteristics. (Will the vehicle be stable while traversing cross-country terrain that is considered acceptable for other similar military vehicles?)

b) To provide ride quality data for the Driver and the Commander.

c) To provide data for calibration of the NATO Reference Mobility Model (NRMM).

d) To provide loads data ("g" level) and strain gage data (truck frame) to assess structural integrity.

3.0 Test Instrumentation

a) Video Tape Recorder (3/4" UMatic - 12V DC preferred).

b) Triaxial accelerometer at C.G. of sprung mass.

c) Vertical accelerometer top of centerline spring - each corner - on frame.

d) Gyro measuring roll at C.G. sprung mass.

e) Strain gages positioned on the upper and lower flanges of frame located near the forward contact point of the simulator with the frame.

f) Vertical accelerometer underneath the Driver's seat.

g) Three axis accelerometer ride quality packages located at Driver's seat and Commander's seat.

h) Vertical accelerometer in axle (bottom spring) on either left or right front corner.

The accelerometers shall be capable of reading acceleration from 2 to 200 Hz. 10 g is max amplitude required except for accelerometer on axle which shall be 20 g (min). The strain gages shall have a maximum amplitude of 2000 μ in./in.

The instrumentation required for each test is shown in Figure A1.

4.0 Physical Characteristics of the Wheeled Vehicle System

4.1 Mass Characteristics

		Center of Gravity		
	(#)	X(1)	Y(2)	Z(3)
Total Mass	50,239	52.7	2.6	70.5

(1) Measured from centerline rear bogie.
(2) Measured from centerline longitudinal axis, positive to right.
(3) Measured from ground.

4.2 Stability Characteristics

The cargo center of gravity on the wheeled vehicle system is higher than most systems. In addition, the center of gravity is offset to the right. Particular caution should be exercised in making turns. Recommended maximum speeds are shown in Figure A2.

4.3 Speed/Mileage Indicator

The speedometer/odometer on the vehicle is calibrated for larger tires. The correction factors shown in Figure A3 should be applied to speeds and mileages.

4.4 Tire Pressure

The following tire pressures shall apply:

	Pressure, psi	
	Front	Rear
Highway	95	75
Cross-Country	75	55
Mud/Snow/Sand	25	25

4.5 Safety for Overturning

The outriggers "training wheels" shall be installed on the ROLAND "wheeled" system for use with significant side slopes (>10 percent).

5.0 Test Conduct

5.1 Ride Quality (Roughness) Tests

a) Configure instrum tation as noted in Figure A1. Videotape roughest course only and rough areas of access roads.

b) Vehicle shall be without training wheels.

c) All instrumentation shall be recorded on magnetic tape. Quick-look Ride Meter also shall be used.

d) Set tire pressure for cross-country.

e) Perform series of tests on courses with varying roughness.

f) When series of tests is complete, rerun roughest course with alternate instrumentation shown in Figure A1.

5.2 Shock Tests

a) Configure instrumentation as noted in Figure A1. Videotape vehicle response for largest shock load only.

b) Set tire pressure for cross-country.

c) Limit "g" level below Driver's seat to 2.5 g .0-Hz filter).

d) Vehicle shall be without training wheels.

e) Obstacles shall be semicircular of 5-1/2-, 8-, and 10-in. radii.

f) Test runs will be made with increasing speed until maximum permitted acceleration is reached. Obstacles will be encountered with both front wheels simultaneously.

g) When tests in f) are complete, change instrumentation to the alternate instrumentation shown in Figure A1 and rerun tests at maximum speed (determined in f)) only.

h) Repeat f) and g) for encountering obstacle on one side only. Observer should note any overturning tendency with increasing speed.

5.3 Side-Slope (Handling) Tests

a) Configure instrumentation as noted in Figure A1. Videotape one run on each side-slope course.

b) Set tire pressure for cross-country.

c) Configure vehicle with training wheels.

d) Drive slope courses in a direction that allows Driver to be on uphill side.

e) Courses shall vary from 5 to 30 percent.

f) Drive each course as follows:

(1) At slowest speed possible.

(2) At maximum speed Driver feels safe but maximum 15 mph.

(3) At maximum safe speed with sinusoidal steering along course.

g) On one selected course of approximately 20 percent slope, repeat f) (1 & 2) when an obstacle is encountered with uphill wheels. Obstacle shall be semicircular 6-in. radius (approximately). Videotape.

h) Drive any "unsurveyed" courses that presented abrupt changes in terrain--typical of deep ruts. Videotape.

i) Boeing Drivers shall drive any courses listed above (Driver training) under the direction of the Test Conductor.

5.4 Turning Tests

a) Configure vehicle without training wheels.

b) Tire pressure set for cross-country.

c) Instrumentation not required except videotape for maximum speed on each turn.

d) Turn radius and maximum speed are as follows. Adjustments may be made to suit existing curves in plant area - refer to Figure A2 for speeds.

Radius, ft	Speed, mph (Recommended)
100	20
200	30
300	35

Note speed correction required for vehicle speedometer (Figure A3).

e) Roads shall be flat (no superelevation) and smooth (no obstacles).

f) All turns shall be to the left.

g) Driver shall start at 10 mph and increase speed in 5-mph increments until maximum speed is reached. Observer shall follow vehicle to note any tendency for instability (overturning).

5.5 Braking Tests

a) Configure vehicle without training wheels.

b) Set tire pressure for highway.

c) No instrumentation required other than stopwatch and measuring tape.

d) Course shall be smooth pavement with 0 percent grade with no curves and TBD* percent grade (maximum downhill).

e) Braking distance shall be measured from initial velocity of 25 mph and maximum velocity on 0 percent slope and TBD percent downhill slope.

6.0 Analysis Requirements

Perform mobility analysis using NRMM considering the following:

a) Use two theaters (West Germany and Mid-East).

b) Compare with HEMTT, another wheeled vehicle, and one tracked vehicle.

* To be determined.

c) Calibrate model as required using test results.

d) Note any degradation in mobility by using 11.00 tires as opposed to using 14.00 tires.

e) Analyze data to define what features of the ROLAND wheeled system limit mobility.

7.0 Data Reports

7.1 Subjective Evaluation

Comments shall be solicited from each Driver on each course immediately after each run under maximum response conditions. Some suggested questions would be:

a) Did you have any feeling of instability of the vehicle?

b) Were you concerned about personal safety?

c) How did this system drive with respect to other wheeled systems you have driven?

d) Did you feel the system is underpowered or acceptable?

e) Was visibility a problem (e.g., rearview mirrors)?

f) Other information offered by Drivers.

Comments may be recorded on cassette tape for convenience in later documentation.

7.2 Test Data

a) Provide test report 30 days after completion of tests.

b) Provide "Quick-Look" report (informal) 15 days after test completion. This report may be in the form of annotated strip charts for selected courses.

c) Provide raw data on magnetic tape 15 days after test completion.

d) Quick-look data and final report data shall be filtered at 100-Hz low pass.

7.3 Analysis Report

Provide analysis report of NRMM results.

Roughness Test (Para 5.1)	Shock Tests (Para 5.2)	Side Slope Tests (Para 5.3)
3 accel - C.G. 1 - vertical acceleration - floor - driver 3 - axis ride quality package driver 3 - axis ride quality package commander Total Channels - 10	3 accel - C.G. 1 - vertical acceleration floor - driver 1 - vertical acceleration commanders seat 1 - vertical acceleration front axle 4 - vertical acceleration frame each corner Total Channels - 10	3 accel - C.G. 1 - vertical acceleration - floor - driver 4 - vertical acceleration - frame each corner 1 - roll gyro 1 - vertical acceleration - commanders seat Total Channels - 10
Alternate Instrumentation as above but Add 4 strain gages Delete lateral and longitudinal at commanders seat Total Channels - 12	Alternate Instrumentation as above but Add 4 strain gages and roll Gyro Delete vertical accelerometer at axle and commanders seat Total Channels - 13	

Figure A1. Test Instrumentation

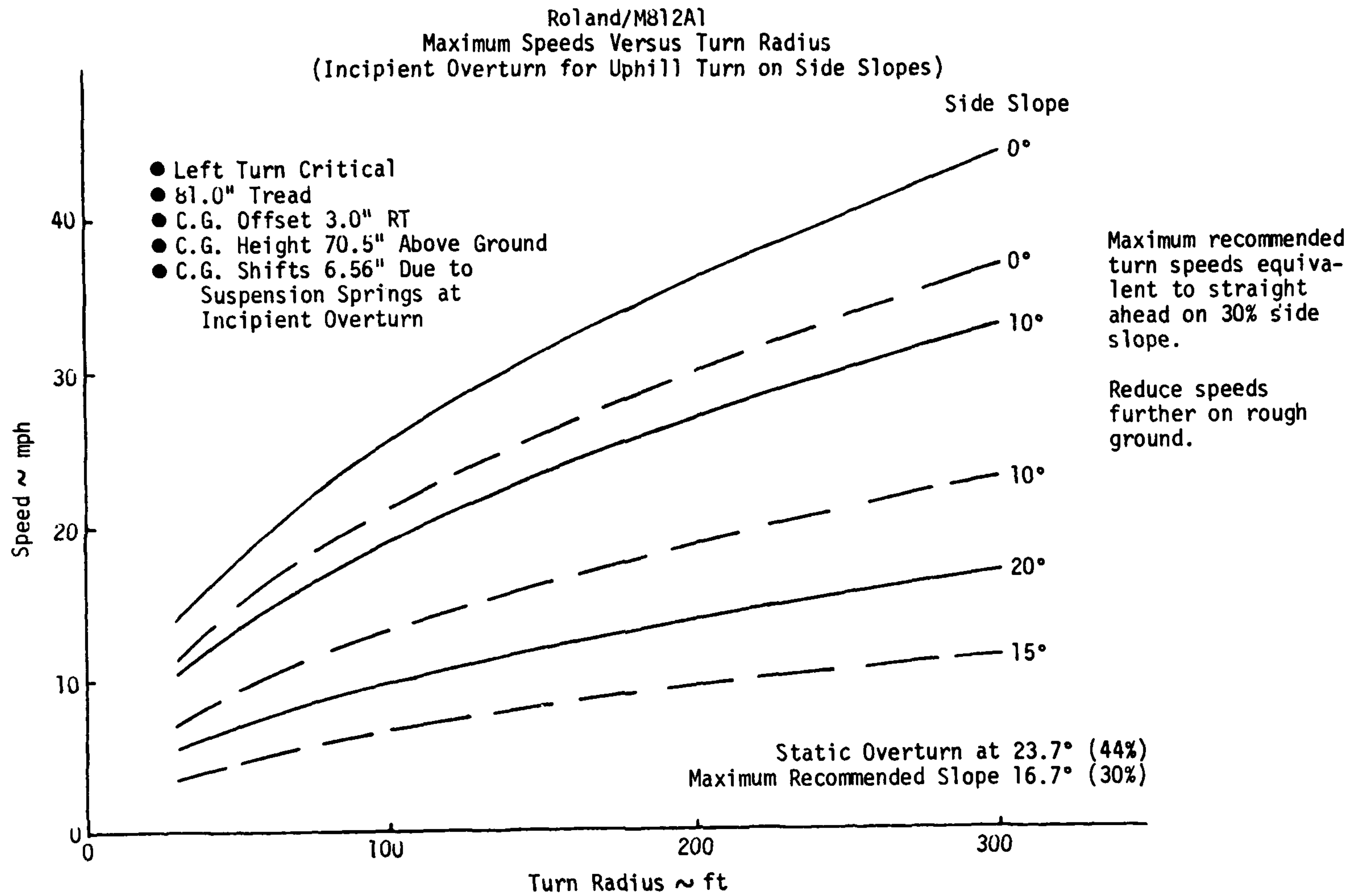


Figure A2. Recommended Turn Speeds
(By Boeing Aerospace Company)

Speed, mph		Mileage	
Indicated	Actual	Indicated	Actual
10	9	25	22
15	13	50	44
20	18	75	66
25	22	100	89
30	27	150	133
35	31	200	177
40	35	250	221
45	40	300	266
50	44	400	354

Correction required due to change in tire size.

Figure A3. Correction Required for Speed and Mileage as Calculated by Boeing Aerospace Company

APPENDIX B: LOCATION OF THE CENTER OF GRAVITY OF THE ROLAND WHEELED VEHICLE SYSTEM

1. The procedures used and the calculations made to determine the center of gravity are presented in this Appendix. Pertinent vehicle characteristics are shown in the following tabulation:

Tire pressures: Front - 75 psi
Rear - 55 psi

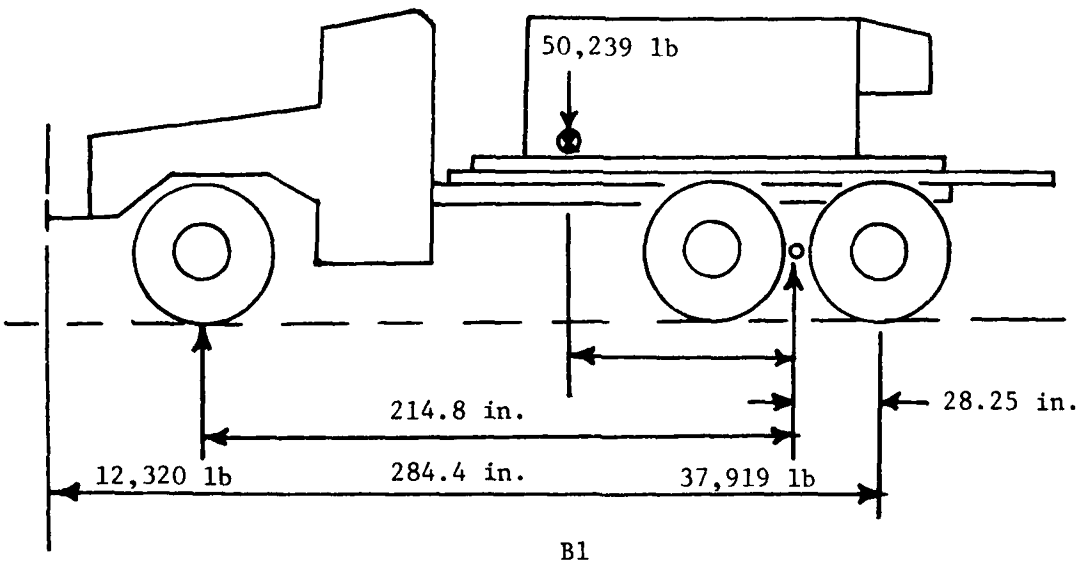
Weight distribution (pounds):

			20,260	
Wheel	6,490	10,040		10,220
Axle	12,320		37,919	
Wheel	5,830	8,724		8,935
			17,659	

Vehicle weight, lb	50,239
Vehicle wheelbase, in.	214.8
Distance from center line of rear bogie to center line of rear wheel, in.	28.25
Tread width, front and/or rear, in.	79.5
Loaded tire radius, in.	20.5

The individual wheel loads were determined using standard highway scales. Basic engineering mechanics equations were used to calculate the location of the center of gravity.

Location of Horizontal Center of Gravity



$$\overset{\curvearrowright +}{\Sigma M_0} = 0 = 12,320(214.8) - 50,239X$$

then

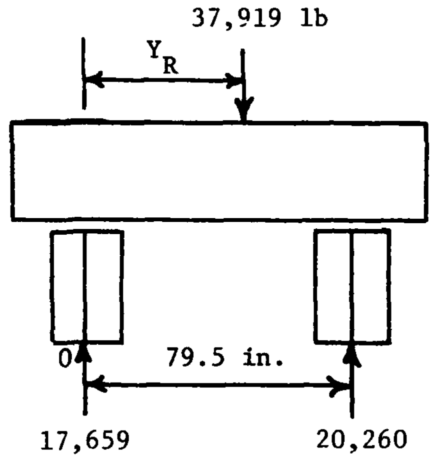
$$X = \frac{12,320(214.8)}{50,239}$$

X = 52.67 in. forward of the center line of the rear bogie

Location of Lateral Center of Gravity

2. The lateral center of gravity was determined for the rear axle and the front axle using the wheel loads and tread widths.

Rear axle lateral center of gravity



Rear view of
rear axle

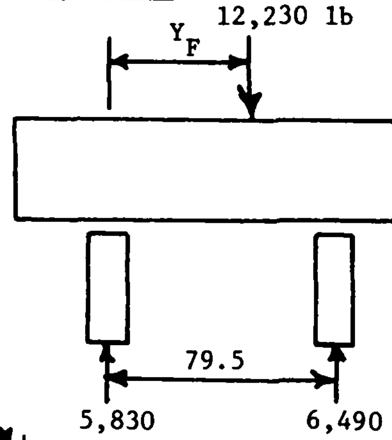
$$\overset{\curvearrowright +}{\Sigma M_0} = 0 = 37,919\ Y_R - 20,260(79.5)$$

then

$$Y_R = \frac{20,260(79.5)}{37,919}$$

Y_R = 42.48 in. from left side

Front axle lateral center of gravity



Rear view of front axle

$$\overset{+}{\Sigma M_0} = 0 = 12{,}320\ Y_F - 6{,}490(79.5)$$

then

$$Y_F = \frac{6{,}490(79.5)}{12{,}330}$$

$$Y_F = 41.88 \text{ in. from left side}$$

3. Using the location of the horizontal center of gravity previously determined, the lateral center of gravity for the total mass of the vehicle can be determined by straight-line interpolation:

Y = geometric lateral center line of the vehicle $= \frac{79.5}{2} = 39.75$ in.

Deviation from Y @ rear axle $= \Delta Y_R = Y_R - Y = 42.48 - 39.75 = 2.73$ in.

Deviation from Y @ front axle $= \Delta Y_F - Y_F - Y = 41.88 - 39.75 = 2.13$ in.

Deviation in ΔY from a straight line $= \Delta Y_R - \Delta Y_F = 0.60$ in.

4. Ratioing the distance from that the horizontal center of gravity is from the rear axle to the total distance from the rear axle to the front axle and multiplying the result by the total deviation gives the deviation at the center of gravity:

$$\text{Ratio} = \frac{52.67}{214.8} = 0.245$$

$$\Delta Y_{CG} = 0.245(0.60)$$

$$\Delta Y_{CG} = 0.147 \text{ in.}$$

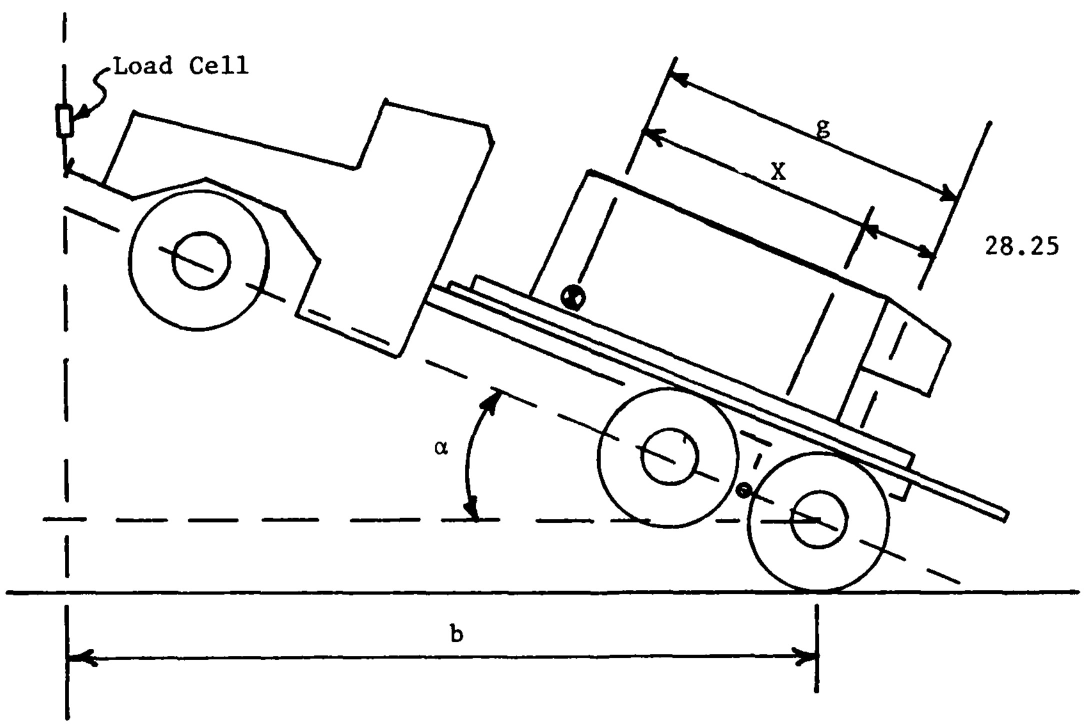
Location of lateral center of gravity from geometric lateral center line of the vehicle = $\Delta Y_R - \Delta Y_{CG}$

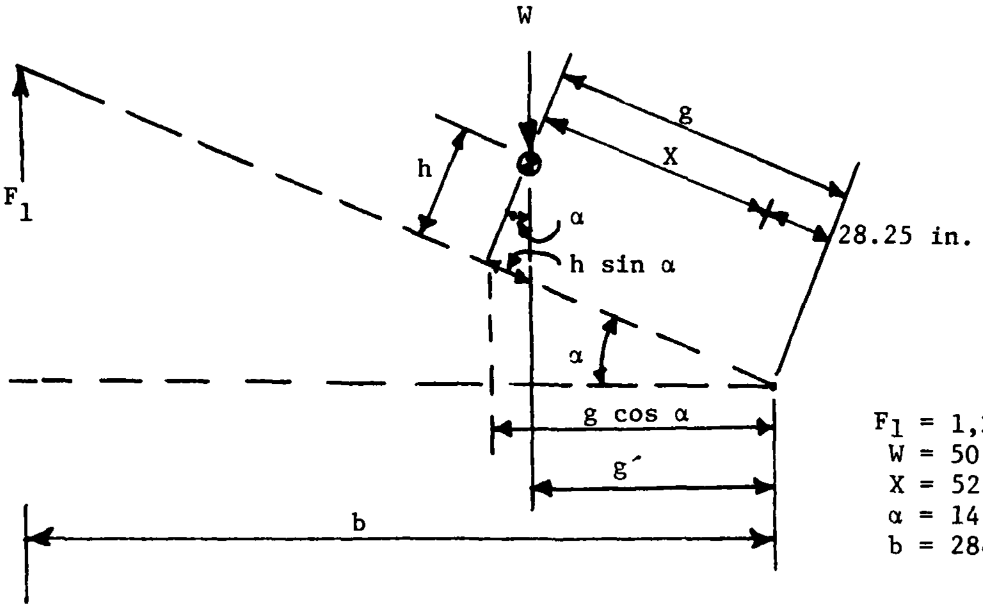
$$= 2.73 \text{ in.} - 0.15 \text{ in.} = 2.58 \text{ in.}$$

Lateral center of gravity is 2.58 in. to the right of the vehicle's geometric center line when facing the rear of the vehicle.

Location of the Vertical Center of Gravity

5. Prior to determining the vertical center of gravity, the front suspension and the rear tandem suspension were locked into their normal horizontal position and a load cell was attached to the front bumper of the vehicle. The front of the vehicle was then lifted into the air and pertinent measurements were made as shown below:





F_1 = 1,200 lb
W = 50,235 lb
X = 52.67 in.
α = 14.7°
b = 284.4 in.

where

H = height of center of gravity from level ground

b = longitudinal distance from center of rear axle to point of application of lifting force

g = longitudinal distance from center of rear axle to horizontal center of gravity

F_1 = total load on load cell

W = total weight, lb

r = loaded wheel radius

α = angle of inclination

h = height of center of gravity from center of rear axle

$$g = X + 28.25$$

but $X = 52.67$

then

$$g = 80.92 \text{ in.}$$

$$\overset{\curvearrowleft +}{\Sigma M_0} = 0 = F_1 b - wg'$$

but $g' = g \cos \alpha - h \sin \alpha$

then

$$h = \frac{g \cos \alpha - F_1 b/W}{\sin \alpha}$$

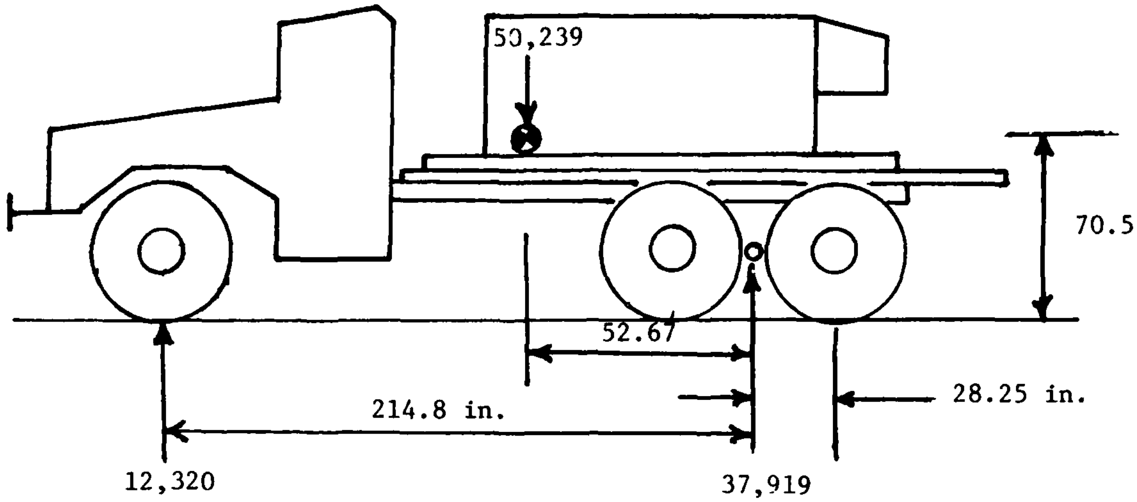
$$h = \frac{80.92 \cos 14.6° - 12,100(272.4)/50,239}{\sin 14.7°}$$

$h = 50.00$ in. above center line of rear axle

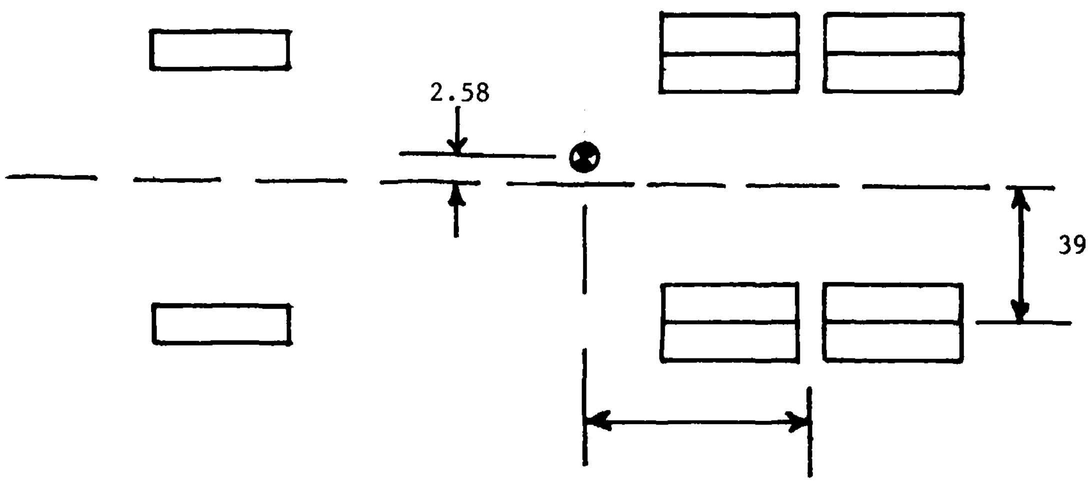
or

$H = 50.00 + 20.5 = 70.50$ in. from ground level

Summary of Center of Gravity Location



Side View



Top View

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Schreiner, Barton G.
Mobility assessment of the ROLAND Wheeled Vehicle System : Report 1 : Results of field tests / by Barton G. Schreiner and Charles E. Green (Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. ; available from NTIS, 1982.
59 p. in various pagings, 30 p. of plates : ill. ; 27 cm. -- (Technical report ; GL-82-12, Report 1)
Cover title.
"November 1982."
"Prepared for U.S. Army Missile Command, Redstone Arsenal under Project No. A11DX588D1Q602."

1. Vehicles, Military. I. Green, Charles E. II. United States. Army Missile Command. III. U.S. Army Engineer Waterways Experiment Station. Geotechnical Laboratory. IV. Title V. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; GL-82-12, Report 1.
TA7.W34 no.GL-82-12 Report 1

END

FILMED

2-83

DTIC